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PHYSICS.—*Altitude by measurement of air pressure and temperature.*[1]

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Measurement of differences in elevation of points on the earth's surface by measuring the atmospheric pressures at the two points is quite old. However, all the additional factors entering into a determination, such as air temperature, humidity, and gravity, were not completely understood until the French mathematician Laplace published the complete formula which bears his name, at least in France.

Until the invention of the aneroid barometer by Vidi in 1847 it was necessary to make the pressure measurements by means of the mercury barometer, which is inconvenient to transport from place to place. The early aneroid instruments were in general unreliable, and progress was slow in eliminating or reducing to reasonable values their many sources of error. However, the elements of the aneroid barometer remain unchanged, although design and workmanship have improved greatly. The advent of the aneroid barometer made convenient the use of this method of measuring altitude.

It should be stressed at the start that the altimeter or aneroid barometer can be used only to measure differences in altitude or elevation. Some base pressure or reference level is assumed either explicitly or implicitly. When the auxiliary altitude scale of the aneroid barometer or the scale of the altimeter is set to zero, it is implied that the subsequent altitude reading of the instrument is above or below the pressure corresponding to the zero reading.

The terms "altimeter" and "aneroid" barometer are often used interchangeably. Both are instruments which measure absolute air pressure. When the pressure scale is graduated in evenly divided pressure units, the instrument will be called an aneroid barometer. It may have an auxiliary altitude scale, but this will be necessarily unevenly divided. On the other hand, when called an altimeter the instrument will have an altitude scale that is graduated in evenly divided units in accordance with the pressure-altitude relation of a selected standard atmosphere. It also may have an auxiliary pressure scale and means for adjusting the zero reading. There is no other fundamental difference in the two instruments.

Almost by necessity a choice must be made between two distinct procedures in measuring altitude by the barometric method. In the first, the air pressures, air temperatures, and other required quantities are measured and the basic formula used to compute the altitude. This procedure usually is followed in cases where the pressure observations are recorded and is customarily used in the computation of atmospheric soundings by meteorologists who have developed short cuts in the computation, which will not be discussed here. It is relatively laborious and time consuming.

In the other procedure, altitude is measured with an altimeter, calibrated to the altitude-pressure relation of a standard atmosphere. In accurate work, additional quantities are observed for use in applying the corrections for deviations in air temperature, humidity, etc., from the assumed standard conditions. The altimeter is used

[1] Address of the retiring president of the Philosophical Society of Washington, delivered at the 1211th meeting of the Society, January 16, 1943. Received April 11, 1944.

both in aircraft during flights and in surveys on land when surveys by transit are not feasible.

We proceed now to a brief discussion of the fundamental formula.

THEORY

Altitude is determined by the following formula (see references 1, 2):

$$H = \int \frac{dP}{g\rho} = KT_m \left[1 + 0.376 \left(\frac{e}{P}\right)_m\right] \cdot \left[1 + \frac{g_s - g_m}{g_s}\right] \log \frac{P_1}{P_2} \quad (1)$$

$$T_m = \frac{\int_{\log P_1}^{\log P_2} T d(\log P)}{\log P_1 - \log P_2} = \frac{\sum T_n}{n} \quad (2)$$

The constant $K = 221.152$ for H in feet and 67.4073 for H in meters.

H = altitude above the pressure level P_1.

P_1 = pressure at ground level.

P = pressure at intermediate levels.

P_2 = pressure at upper level; all in the same units of pressure;

ρ = air density;

T_m = mean temperature in °K(= 273 + t°C) of the air column between pressure levels P_1 and P_2.

T_n = the air temperature at equally spaced intervals of $\log P$ or $K \log (P_1/P_2)$ between P_1 and P_2.

n = number of selected equal intervals between P_1 and P_2.

e = water vapor pressure in same units as P.

$(e/P)_m$ = mean value for air column between P_1 and P_2.

g_s = standard value of gravity.

g_m = value of gravity at the midpoint of the air column between P_1 and P_2.

The altitude above sea level equals $H + h$ where h is the elevation above sea level of the lower pressure level.

The formula as given involves the following assumptions:

(*a*) Air obeys the gas law, $pv = mRT$.

(*b*) The composition of the atmosphere is the same at all altitudes.

(*c*) The air is in vertical equilibrium, i.e., no vertical currents.

The following values of the constants were used in evaluating K:

(*a*) Air density at 0°C and 760 mm of mercury, 1.2930 kg/m³.

(*b*) Standard value of gravity, 980.665 cm/sec².

(*c*) Density of mercury at 0°C, 13.5951 g/cm³.

(*d*) The air is assumed dry.

Formula (1), or its equivalent forms, is used in making precise determinations of the altitude. The necessary observations are:

(*a*) The air pressures at the lower and upper levels, measured simultaneously and on the same vertical line, or corrected to obtain simultaneity and verticality.

(*b*) The air temperature and corresponding air pressure at intervals from the lower to the upper level, also measured or corrected to obtain simultaneity. The intervals must be sufficiently close to obtain an accurate picture of the temperature distribution.

(*c*) The humidity, and the corresponding air temperature and air pressure, measured at intervals from the lower to the upper level.

(*d*) The values of gravity at the lower and upper level obtained usually by computation from available data.

Since the atmosphere is not generally in equilibrium, the air pressure, temperature, and humidity vary with time and place, and since observations of these elements in general can not be made simultaneously in the same vertical line, consideration must be given to methods of correcting the observed data. First, observations should be made, when possible, when atmospheric conditions are reasonably stable; observations during line squalls, wind shifts, and thunderstorms should be avoided.

Continuous measurements of the air pres-

sure and air temperature at the lower level may be made in a net around the point at which the pressure at the upper level is measured, in which case the proper pressure and temperature at the lower level are obtained by interpolation in time and location. Since the above procedure is often impracticable, the air pressure and temperature are usually measured continuously at one point only, in which case the observations available are used as circumstances permit, to bring the pressures and temperatures at the two levels into simultaneity and verticality. Field conditions under which observations are made, either in surveying or in aircraft flights, are far from ideal, so that some data are often lacking; in this case the computer can usually fill the gap from routine observations by the Weather Bureau office serving the locality.

The required temperature observations offer more difficulty than those of pressures; first, because the temperature changes more rapidly with time, especially near the ground; and second, because, particularly in surveying, the air column is often fictitious, that is, the lower or reference level vertically below the point of observations at the upper level is underground. There is further the fact that local thermal gradients exist near the ground, particularly in broken country, which introduce inaccuracy into the determination of mean temperature. It may be stated here that air currents along the ground which arise from thermal gradients have a vertical component on mountain sides, and therefore introduce errors into the altitude determination, found by Rühlman (*1*)[2] to be of the order of 2 percent.

It is obvious from the foregoing that the time interval between the initial observations at the lower level and the final observations at the upper level should be as short as possible.

The observations to obtain the humidity term in formula (1) require only that of humidity in addition to those of temperature and pressure already discussed. Fortunately, the humidity term is of minor importance, rarely exceeding 1.0 percent in amount, at summer temperature, and rapidly reducing in amount with reduction in air temperature. In surveying, its measurement to sufficient accuracy offers no difficulty and may often be made only at the lower level station without loss in accuracy.

Approximate altitude formula.—In many cases pressure and temperature data are sufficient for the accuracy required or are all that are available. The altitude is then given by

$$H = KT_m \log \frac{P_1}{P_2}, \qquad (3)$$

where the notation is as given for formula (1) and the observations needed are those listed under (*a*) and (*b*) above.

Alternate form of formula.—Meteorologists commonly use formulas (1) and (2) in somewhat different form, so that the computations can be made in steps up to the highest altitude. This is, neglecting gravity and humidity correction terms, which are the same as given in formula (1),

$$H = \sum_1^n h = K \sum_1^n T_m \log \frac{P_r}{P_s}, \qquad (3a)$$

where n equals the number of intervals in the air column between P_1 and P_2 usually divided at points where the rate of change of temperature with respect to log P, or lapse rate, changes in value.

$$T_m = \frac{T_r + T_s}{2}.$$

T_r and T_s are the temperatures in °K at the lower and upper levels of each altitude interval respectively.

P_r and P_s are the air pressures corresponding to T_r and T_s. Discussion in this paper will be limited to formulas (1) and (3).

Computation of mean temperature.—To compute the mean temperature from adequate observations, when the altitude to be determined is large, say above 500 to 1,000 feet, plot the observed temperature at pressure P against log P or K log (P_1/P), whichever is more convenient (*2*). It is evident from formula (2) that the mean temperature is the area included in the curve and

[2] Italic numbers in parentheses refer to literature cited at end of paper.

the ordinate $T=0$, divided by $\log P_1 - \log P_2$. The area can be determined by a planimeter or by graphical integration. The computation is made more conveniently by other methods. If the curve is linear, the mean temperature is the temperature at the midpoint of the log P ordinate. Otherwise, divide the curve into a number of equal intervals of log P. The decision as to the number of intervals n is a matter of judgment based upon the degree of irregularity of the temperature curve and a balance of the accuracy of the data against the accuracy of the determination. The more intervals, the greater the possible precision. For each interval of log P the mean temperature is obtained by inspection, and usually is the temperature at the midpoint. The average of the mean temperatures T_m of the intervals is the mean temperature T_m of the air column.

When the altitude difference is small, it is often sufficiently accurate to take as the mean temperature the air temperature measured at the place and time of measurement of the pressure P_2. As a further refinement the average of the temperatures measured simultaneously with P_1 and P_2 at the two points of observation can be taken as the mean temperature.

Methods of computing approximately the mean air temperatures for large altitude differences have been proposed and are in use mainly because of difficulty, or possibly negligence, in obtaining the data necessary for an accurate computation. All these methods give mean temperatures which are more or less inaccurate when a temperature inversion exists in the air column between pressure levels P_1 and P_2, or in general if the temperature lapse rate is not constant between P_1 and P_2.

A commonly used approximation is

$$T_m = \frac{T_1 + T_2}{2} \tag{4}$$

where T_1 and T_2 are the temperatures measured at levels P_1 and P_2 respectively.

Another approximation is

$$T_m = T_1 - \frac{aZ}{2} = T_2 + \frac{aZ}{2} \tag{5}$$

where a is an assumed temperature lapse rate, commonly 2°C. per 1,000 feet, and Z, the altitude in the standard atmosphere to which the altimeter is graduated.

It will be seen that formula (4) involves making only two observations of temperature, and formula (5) one observation, either at level P_1 or P_2, usually most conveniently at P_2.

There is also another approximation which may be of value in aircraft because of relative ease in computation. This is

$$T_m = \frac{T_1 + T_2 + T_3 \cdots T_n}{n} \tag{6}$$

where T_1 and T_n are the air temperatures at the lower and upper levels respectively, and T_2, T_3, etc. are temperatures at intermediate levels, equally spaced in altitude, as measured by an altimeter.

Humidity correction.—The additive correction C_h for humidity is given by the relation

$$C_h = 0.376 \left(\frac{e}{P}\right)_m H_e \tag{7}$$

and the altitude H determined by pressure, temperature and humidity is

$$H = H_e + C_h$$

where $(e/P)_m$ is the mean value of the ratio of the water vapor pressure to the corresponding air pressure and H_e is the altitude determined by the pressure and temperature data.

The magnitude of the humidity correction given by formula (7) for the case when the relative humidity is 100 percent and for five ground level temperatures is given in Fig. 1. The temperature lapse rate is assumed the same as for the U. S. standard atmosphere, that is, 1.98°C. per 1,000 feet. Lines showing a correction of 0.5 and 1 percent of the altitude H_e are also shown on the chart.

It is seen that the amount of humidity correction rises rapidly with air temperature and that the error tends to become constant in amount at high altitudes and low ground level temperatures. The actual humidity corrections are less than those shown in Fig. 1, since 100 percent relative

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humidity at all altitudes is not common.

Actually the vapor pressure of water in the atmosphere tends to remain constant for a considerable altitude, but the relative humidity increases up to the altitude at which condensation takes place, indicated by the presence of a cloud. This fact makes it possible to calculate with some accuracy from one value of the relative humidity the humidity corrections for moderate altitudes, not exceeding as a maximum the height of the underside of the cloud layer.

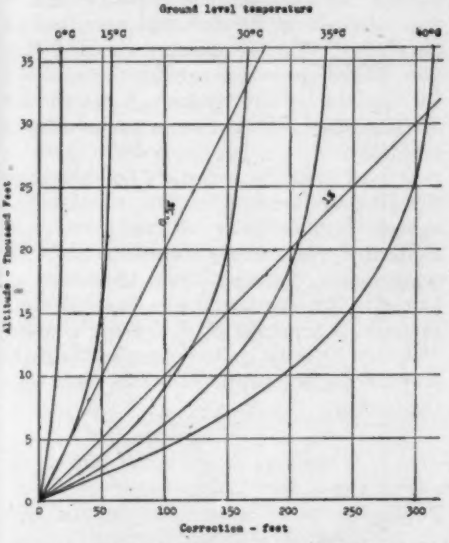

Fig. 1.—Humidity correction $C_h = 0.376(e/p)_m H_c$ for saturated air. The air temperature $t = t_0 - .00198h$, where t_0 is the air temperature at the ground level marked on the particular curve and h is the altitude. The straight lines give the humidity correction as a designated percentage of the altitude.

Gravity correction.—The correction for deviation from standard gravity, g_s, 980.665 cm/sec² is as follows:

$$C_g = \frac{g_s - g_m}{g_m} H_c \qquad (8)$$

where g_m is the mean value of gravity for the air column and H_c is the altitude determined by pressure, temperature, and humidity measurements. The altitude H corrected for temperature, humidity, and gravity is $H = H_c + C_g$

The mean value of gravity equals

$$g_m = g_l - \frac{K(H+2h)}{2} \qquad (9)$$

where g_l is the gravity at sea level, obtained from observed or computed data published in the Smithsonian Meteorological Tables (*3*) or by the U. S. Coast and Geodetic Survey; h is the elevation above sea level of pressure level P_1; $(H+h)$ is the elevation above sea level of pressure level P_2, practically H_c+h; and K is a constant which equals 0.000094 (*3*) when H and h are in feet.

The corrections at the Equator, at latitude 45°, and at the poles are as follows for the case where h is zero:

GRAVITY CORRECTION, C_g

Altitude	Equator		Latitude 45°		Pole	
Feet	*Feet*	*%H*	*Feet*	*%H*	*Feet*	*%H*
1,000..	+ 2.7	+0.27	+ 0.1	+0.009	− 2.5	−0.25
20,000..	+ 74	+0.37	+20	+0.098	−32	−0.16
30,000..	+123	+0.41	+43	+0.145	−36	−0.12

Accuracy of barometric formula.—The question arises naturally as to the accuracy of the barometric formula. This question has been considered by a number of investigators, notably Rühlman (*1*), who checked the formula for two years in the Swiss Alps. In 1935 a balloon flight to 72,395 feet was made by Maj. A. W. Stevens and Capt. O. A. Anderson under the auspices of the National Geographic Society and the Army Corps. During the latter flight accurate and complete barometric data were obtained, and photographs made vertically downward from the balloon, from both of which the altitudes were determined. The balloon altitudes were also measured by triangulation from the ground. A comparison of the data given by Brombacher and Houseman (*4*) is shown in Fig. 2. About 60 photogrammetric and 11 triangulation altitudes are shown in the figure against a curve of balloon altitude against time determined from the barometric data.

The agreement in the altitudes by the three independent methods is quite good and leads to confidence in the barometric

method up to at least 72,000 feet. Comparing the photogrammetric and the barometric altitudes, the average difference is 0.36 percent; on the average the barometric altitude is 93 feet lower.

Standard atmospheres.—Since aneroid barometers and altimeters are primarily pressure measuring instruments, it is essential to choose some altitude-pressure-temperature relation to which they can be calibrated in units of altitude. A large number of these relations, based on a selected condition of the atmosphere, known as a standard atmosphere, have been and are being used. For aviation altimeters, the standard atmospheres now in use are national or international standards; for aneroid barometers and surveying altimeters the standard atmosphere has been selected by the manufacturer or the buyer and, in one case, Germany, it is the national standard.

In general, aneroid barometers equipped with an altitude scale which are commercially available in this country and Great Britain are calibrated to Airy's pressure altitude relation; some are calibrated to the obsolete United States altimeter calibration standard; and others bought under Government specifications are calibrated to the altitude-pressure relation for English units given in the Smithsonian Meteorological Tables. The latter instruments are, strictly speaking, altimeters, but are used only on the ground. In addition to the above calibration standards, there is also another, found on Paulin aneroid barometers made in Sweden, of which there are a number in this country. However, some Paulin instruments in use in this country are calibrated to one of the other above-mentioned relations. The German calibration standard was adopted as the national standard on October 1, 1929. It should be stated that the altitude-pressure relations considered here do not by any means exhaust the list of those used; others are in use in France and Italy.

It may thus be necessary to determine the altitude-pressure relation to which an aneroid barometer or altimeter has been calibrated, particularly if corrections for air temperature deviation from the value assumed in the standard are to be applied, or, in fact, if accurate altitudes are desired. This can be done quite conveniently if the aneroid barometer, or altimeter, has both

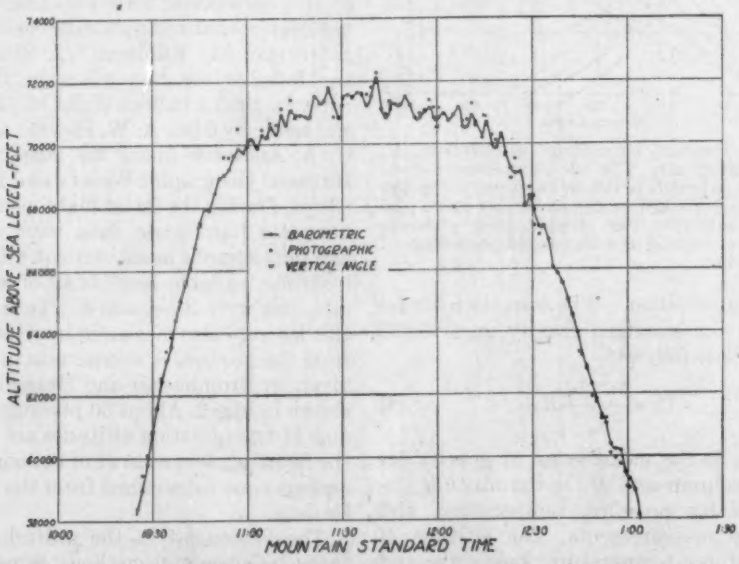

Fig. 2.—A comparison of altitudes of stratosphere balloon Explorer II determined by the barometric formula, by vertical camera photographs, and by theodolite observations.

an altitude and pressure scale. In this case, values of the altitude from the barometer can be checked against values at the same pressure in available tables.

The situation for aviation altimeters is comparatively quite simple. The standard atmosphere adopted by the International Commission for Aerial Navigation (ICAN) in 1924 is used with some modifications, usually minor, by the United States, British Empire, France, Germany, Italy, Japan, and perhaps other nations.

The formulas and constants defining these various standard atmospheres are given below, together with equivalent formulas to facilitate easy comparison. The standard value of gravity given for each atmosphere enters into the evaluation of the constant term or exponent of the altitude formula.

Notation.—In the formulas for the standard atmosphere the symbols have the following definitions:

Z = altitude in the standard atmosphere; if measured above standard ground level pressure P_0 it is called pressure altitude.
P = air pressure at altitude Z.
P_0 = air pressure at ground level of standard atmosphere.
g_s = standard value of gravity.
ρ_0 = density at ground level of standard.
T_{ms} = mean temperature of air column between P and P_0 in standard.
T_s = temperature of air at altitude Z.
a = standard rate of decrease of temperature with altitude Z, or the lapse rate.

Smithsonian.—Altitude-pressure tables in English units given in the Smithsonian Meteorological Tables (*3*) are computed from the following formulas and constants:

$$Z = 62583.6 \frac{T_{ms}}{283} \log \frac{P_0}{P} \text{ feet} \qquad (10)$$

$T_{ms} = 283$ °K
$P_0 = 29.90$ inches of mercury $= 759.46$ mm of mercury
$= 1012.53$ millibars (mb)
$g_s = 980.665$ cm/sec²
$\rho_0 = 1.293$ kg/m³ at 0°C. and 760 mm of mercury

Note that $T_{ms}/283 = 1$. This term is retained in the formula in order to facilitate comparison with other standard atmospheres.

If T_{ms} is in °R ($459.4 + t$°F.), the temperature term 283 in formula (10) becomes 509.4 °R. To obtain Z in meters, change the constant 62583.6 to 19075.5. Dry air has been assumed.

Altitude pressure tables are also given based on $P_0 = 760$ mm of mercury and $T_{ms} = 273$°K (0°C.), but no case of surveying altimeters calibrated to these tables is known.

Airy.—The altitude-pressure relation proposed by Sir George Airy (*5*) in 1867 is unique in that a high value of the pressure was taken at zero altitude in order to avoid minus altitudes under ordinary conditions of use.

$$Z = 62759 \frac{T_{ms}}{283} \log \frac{P_0}{P} \text{ feet} \qquad (11)$$

$T_{ms} = 283$ °K
$P_0 = 31.00$ inches of mercury.

The constant 62759 is about 0.3 percent higher than that now accepted for formulas based on dry air; therefore altitudes indicated on instruments calibrated to it should be reduced by 0.3 percent, if accurate values are desired, as would be the case if temperature and other corrections are applied.

Obsolete U. S. Aeronautic.—This altitude-pressure relation, used before 1926 (*2*) in calibrating aviation altimeters, has been and perhaps still is used for calibrating altimeters and aneroid barometers used in altitude measurement in surveying. It is defined below:

$$Z = 62900 \frac{T_{ms}}{283} \log \frac{P_0}{P} \text{ feet} \qquad (12)$$

$T_{ms} = 283$ °K
$P_0 = 29.90$ inches of mercury.

The relation is the same as that given in the Smithsonian Meteorological Tables except that the constant 62583.6 was increased 0.5 percent to include a correction for "average" humidity. At winter temperatures this correction is too high; at summer temperatures, too low. Therefore, if readings from instruments so calibrated are to

be corrected for all errors, it is best to start by deducting 0.5 percent from the indicated altitude.

Paulin (Swedish).—This calibration may be defined as follows:

$$Z = 62796 \frac{T_m}{283} \log \frac{P_0}{P} \text{ feet} \quad (13)$$

$T_m = 283$ °K

$P_0 = 762$ mm of mercury

It will be seen that the constant 62796 is 0.33 percent higher than the value given for formula (10). The remarks made under formula (12) apply.

German (surveying instruments).—This standard was officially adopted (*6*) for calibrating aneroid barometers and altimeters for surveying on October 1, 1929, but is limited to 5,000 meters. This standard was also used to calibrate aviation altimeters with an altitude limit of 10,000 meters (32,808 feet), but has been superseded for this purpose by the ICAN. The definition follows:

$$P = 762\left(1 - \frac{0.005Z}{283}\right)^{5.33} (Z \text{ in meters}) \quad (14)$$

or

$$Z = 62603 \frac{T_m}{283} \log \frac{P_0}{P} \text{ feet} \quad (15)$$

$T_s = 283 - 0.005Z$ °K

$P_0 = 762$ mm of mercury

$g_s = 980.6$ cm/sec²

The value of the constant 62603 differs from the accurate value given in formula (10) by 0.03 percent, which is negligible for most purposes.

ICAN standard.—This standard (*7*) adopted by the International Committee for Aerial Navigation is the basis of the standards now generally used for calibrating altimeters. Most countries have made only minor modifications, so that for most practical purposes the same standard can be said to be used by all. It is defined here for reference.

Up to 11,000 meters (36,089 feet):

$$\frac{P}{P_0} = \left[\frac{T_s}{288}\right]^{5.256} \quad (16)$$

$T_s = (288 - aZ)$ °K (16a)

$a = 6.5$°C/km $= 0.0019812$ °C/foot (16b)

$P_0 = 760$ mm of mercury (16c)

Above 11,000 meters:

$$Z = 11000 + 14600 \log \frac{P_{11}}{P} \text{ meters} \quad (17)$$

$T_s = -56.5$°C.

$P_{11} = 169.595$ mm of mercury (at 11,000 m).

For all altitudes:

$g = 980.62$ cm/sec²

U. S. Aeronautic.—This standard atmosphere (*8*) (*9*), used since 1926 in calibrating aviation altimeters, and also adopted as the standard atmosphere for all aeronautic purposes in the United States, is a slight modification of the ICAN. The air temperature is assumed to vary uniformly with altitude (6.5°C. per km) until a temperature of −55°C. (instead of −56.5°C.) is reached. Above this level the temperature is assumed constant at −55°C. Its definition follows:

Up to 35,332 feet:

$$Z = 63691.8 \frac{T_m}{288} \log \frac{P_0}{P} \text{ feet} \quad (18)$$

or

$$P = P_0\left[\frac{T_s}{288}\right]^{5.2561} \quad (19)$$

$T_s = 288 - aZ$ °K (18a)

$a = 0.0019812$ °C/foot $= 6.5$ °C./km (18b)

$$T_m = \frac{aZ}{288 \ln \frac{}{T_s}} \quad (18c)$$

$P_0 = 760$ mm of mercury $= 29.921$ inches of mercury $= 1013.25+$ mb.

$\rho_0 = 1.2255$ kg/m³

Above 35,332 feet:

$$Z - 35332 = 48211.1 \log \frac{P_{35}}{P} \text{ feet} \quad (20)$$

$T_m = 218$ °K

$P_{35} = 175.898$ mm of mercury

For all altitudes:

$g_s = 980.665$ cm/sec²

To compare with the SMT formula (10), formula (18) can be written:

$$Z = 62586.0 \frac{T_m}{283} \log \frac{P_0}{P}. \quad (21)$$

The values of the constants for the two standard atmospheres, 62583.6 and 62586, are in practical agreement, so that altitudes obtained from readings on instruments calibrated to either formula, after applying correction for deviation of actual mean temperature from that of the respective standard, will be in agreement.

The constant K given in formula (1), when multiplied by 283 to obtain the formula in the same form as in formula (21), is also 62586.0.

The altitude in the standard atmosphere defined by formulas (18) and (20), when $P_0 = 760$ mm of mercury, is called the pressure altitude.

British Aeronautic.—This standard atmosphere (*10*) is also a slightly modified version of the ICAN. The air temperature is assumed to vary 1.98°C. per 1,000 feet of altitude, which is not exactly 6.5°C. per km, the ICAN value. Its definition follows.

Up to 36,090 feet:

$$\frac{P}{P_0} = \left[\frac{T_s}{288}\right]^{5.256} \tag{22}$$

or

$$Z = 63721 \frac{T_{ss}}{288} \log \frac{P_0}{P} \tag{23}$$

$$T_s = 288 - aZ \text{ °K} \tag{22a}$$

$$a = 0.00198 \text{ °C/foot} = 6.496 \text{ °C./km} \tag{22b}$$

$$T_{ss} = \frac{aZ}{\ln \frac{288}{T_s}} \tag{23a}$$

$P_0 = 1013.2$ mb $= 760$ mm of mercury

Above 36,090 feet:

$$Z = 36090 + 47900 \log \frac{P_{36.5}}{P} \tag{24}$$

$$T_{ss} = 216.5 \text{ °K} \tag{24a}$$

$P_{36.5} = 226.3$ mb $= 169.7$ mm of mercury

For all altitudes:

$g_s = 980.62$ cm/sec²

French Aeronautic.—This standard (*11*) was first proposed by Toussaint and adopted in France in 1920. Later the ICAN adopted it, since when it has been known as the ICAN standard. It differs from the ICAN given above only in that the exponent of equation (16) is 5.255, instead of 5.256. For all practical purposes the pressure-altitude tables are identical with those of the ICAN.

German Aeronautic.—This standard atmosphere (*12*) differs from ICAN standard as given in formulas (16) and (17) in that the exponent used is 5.26 instead of 5.256. The air is assumed dry with a specific weight of 1.225 kg/m³ at sea level. For all altitudes, $g = 980.62$ cm/sec².

At 35,000 feet the pressure is 178.5 mm of mercury; this is 0.2 mm of mercury less than in the ICAN standard, equivalent to 24 feet difference at 178.7 mm of mercury. This altitude difference for a given pressure, German compared to ICAN standard, becomes less at lower altitudes but will be constant at 24 feet at altitudes above 35,000 feet.

Japanese Aeronautic.—This standard atmosphere (*13*) is basically the ICAN.

Up to 11,000 meters:

$$P = 760\left(\frac{288 - 6.5Z}{288}\right)^{5.253}.$$

Above 11,000 meters:

$$Z = 11000 + 14600 \log \frac{P_{11}}{P}$$

$P_{11} = 169.74$ mm of mercury

$T_s = 216.5$°K (-56.5°C.)

At all altitudes:

$g = 980.00$ cm/sec², in the altitude formula;

$g = 980.665$ cm/sec², for other purposes.

At a pressure of 175.898 mm of mercury, the U. S. altitude is 35,332 feet, the Japanese, 35,346 feet; at 169.74 mm of mercury the U. S. altitude is 36,079 feet, the Japanese, 36,089 feet (11,000 m). The above differences are less at lower, and constant at about 10 feet at greater, altitudes.

Altitude-pressure tables.—Altitude-pressure data for the various altimeter calibration standards are given in Tables 1 and 2. The calibration standards covered in Table 1 are commonly used for aneroid barometers and surveying altimeters; in Table 2 are given the United States, British, and the ICAN calibration standards for aviation altimeters.

Comparison of standard atmospheres.—It will be seen that the standard atmospheres differ mainly (*a*) in the altitude-temperature assumption, and to a minor extent (*b*) in the standard value of the acceleration

TABLE 1.—ALTITUDE-PRESSURE TABLES USED IN CALIBRATING ANEROID BAROMETERS

Altitude	Pressure in inches of mercury				
	Airy's Scale	S.M.T. Table 51	U.S. altimeter before 1926	Paulin (Swedish)	German
Feet	*10°C.*	*10°C.*	*10°C.*	*10°C.*	$T=f(z)$
−1,000	—	31.021	31.02	—	—
− 500	—	30.455	30.45	—	—
0	31.000	29.900	29.90	30.00	30.00
500	—	29.355	—	—	—
1,000	29.883	28.820	28.83	28.92	28.91
1,500	—	28.295	—	—	—
2,000	28.807	27.820	27.79	27.88	27.86
2,500	—	27.272	—	—	—
3,000	27.769	26.775	26.79	26.88	26.84
3,500	—	26.287	—	—	—
4,000	26.769	25.808	25.83	25.91	25.85
4,500	—	25.338	—	—	—
5,000	25.804	24.875	24.90	24.97	24.90
6,000	24.875	23.977	24.00	24.08	23.97
7,000	23.979	23.110	23.14	23.21	23.08
8,000	23.115	22.276	22.31	22.37	22.21
9,000	22.282	21.472	21.51	21.57	21.37
10,000	21.479	20.696	20.73	20.79	20.56
11,000	20.706	19.948	19.99	20.04	19.77
12,000	19.959	19.228	19.27	19.32	19.01
13,000	19.240	18.533	18.58	18.65	18.27
14,000	18.548	17.864	17.91	17.96	17.56
15,000	17.880	17.218	17.27	17.31	16.88
16,000	17.235	16.596	16.65	16.69	16.21
17,000	16.615	15.997	16.05	16.08	15.57
18,000	16.016	15.419	15.47	15.51	14.95
19,000	15.439	14.862	14.91	14.95	14.35
20,000	14.883	14.325	14.38	14.41	—
21,000	14.347	13.808	13.86	—	—
22,000	13.830	13.309	13.36	—	—
23,000	13.332	12.828	12.88	—	—
24,000	—	12.365	12.42	—	—
25,000	—	—	11.98	—	—
30,000	—	—	9.97	—	—
35,000	—	—	8.30	—	—
40,000	—	—	6.91	—	—

of gravity, and (c) in the physical constants entering into the constant term of the altitude equation even when reduction is made to a common basis of ground level pressure and temperature. In most cases the values of altitude obtained will not differ significantly if the appropriate values of the temperature, gravity, and humidity corrections are applied.

The values of the physical constants embodied in the constant term in the Smithsonian, U. S. Aeronautic, and ICAN standard atmospheres are equivalent and are believed accurate.

It will be noted that the values of standard gravity differ somewhat for the various standard atmospheres. In particular, the International Standard (980.665 cm/sec²) is used in the United States, while European countries use the above value adjusted to give the value assumed to be that at latitude 45° (980.62 cm/sec²). The value of gravity used affects the constant term (or exponent of ICAN) of the formula; the difference is 1:22000 in the altitudes corre-

TABLE 2.—STANDARD ALTITUDE-PRESSURE TABLES USED IN CALIBRATING AVIATION ALTIMETERS

Pressure altitude 1,000 feet	United States			British		ICAN
	Mm of mercury	Inches of mercury	mb	Mm of mercury	mb	Mm of mercury
−1	787.9	31.02	1050.4	—	—	—
0	760.0	29.921	1013.3	760.0	1013.2	760.0
1	732.9	28.86	977.1	732.9	977.1	—
2	706.6	27.82	942.1	706.6	942.1	—
3	681.1	26.81	908.1	681.1	908.1	—
4	656.3	25.84	875.0	656.4	875.1	—
5	632.3	24.89	843.0	632.3	843.0	632.3
6	609.0	23.98	811.9	609.1	812.0	—
7	586.4	23.09	781.8	586.4	781.8	—
8	564.4	22.22	752.5	564.5	752.6	—
9	543.2	21.38	724.2	543.3	724.3	—
10	522.6	20.58	696.7	522.6	696.8	522.6
11	502.6	19.79	670.1	502.7	670.2	—
12	483.3	19.03	644.3	483.3	644.4	—
13	464.5	18.29	619.3	464.6	619.4	—
14	446.4	17.57	595.1	446.4	595.2	—
15	428.8	16.88	571.7	428.9	571.8	428.8
16	411.8	16.21	549.0	411.9	549.1	—
17	395.3	15.56	527.0	395.4	527.2	—
18	379.4	14.94	505.8	379.9	506.0	—
19	364.0	14.33	485.3	364.2	485.5	—
20	349.1	13.75	465.4	349.2	465.6	349.1
21	334.7	13.18	446.2	334.8	446.4	—
22	320.8	12.63	427.7	321.0	427.9	—
23	307.4	12.10	409.8	307.5	410.0	—
24	294.4	11.59	392.5	294.5	392.7	—
25	281.9	11.10	375.8	282.0	376.0	281.9
26	269.8	10.62	359.7	269.9	359.9	—
27	258.1	10.16	344.1	258.2	344.3	—
28	246.9	9.720	329.2	247.0	329.3	—
29	236.0	9.293	314.6	236.2	314.9	—
30	225.6	8.880	300.8	225.7	300.9	225.6
35	178.7	7.036	238.2	178.8	238.4	178.7
40	140.7	5.541	187.6	140.7	187.6	140.5
45	110.8	4.364	147.7	110.6	147.5	110.5
50	87.30	3.436	116.4	87.00	116.0	86.9

sponding to a given pressure, ordinarily negligible.

In these countries also the respective values of standard gravity are used to define the inch or millimeter of mercury. Thus the values of pressure in the United States are for millimeters or inches of mercury at a gravity of 980.665 cm/sec², and for the other countries at 980.62 cm/sec²; to convert to pressures based on 980.665 cm/sec² the pressures based on 980.62 cm/sec² must all be reduced in the ratio 1:22000, equivalent to an altitude difference of about 1.3 feet, independent of altitude. This difference is usually negligible.

In comparing altimeters calibrated to the ICAN standard atmosphere, or modified ICAN, this difference in standard gravity must be considered in its effect both on the standard atmosphere and on the standard of pressure. The difference in the gravity used in the United States and European standard atmosphere causes a difference in the indicated altitude of one part in 22,000, as has been said. The difference in the standard of pressure causes a constant difference in indication of about 1.3 feet; when the pressure scales of a U. S. and a British altimeter are both set to read 760 mm of mercury or its equivalent, the British altimeter will read 1.3 feet lower. Other differences in the standard atmospheres and the variation of altimeter readings at a given pressure make the differences in this respect insignificant.

The pressure in millibars given for the British Aeronautic standard in Table 2 is taken from a British publication (*10*); the conversion to millimeters of mercury is made based on a gravity of 980.665 cm/sec² in order to obtain a direct comparison with U. S. Aeronautic standard.

Determining altitude with altimeters.—As has been stated, when pressure observations, not altitude, are made, the altitude is determined by computation, using barometric formula (1) or (3).

When an altimeter is used, thus securing readings in altitude units, the general relation to be used in computing altitudes is obtained by substituting for $\log P_1 - \log P_2$ in formula (1) its value obtained from the formula defining the standard atmosphere, as for example formula (10) or (18). There is obtained:

$$H = Z \frac{T_m}{T_{m_s}} \left[1 + 0.376 \left(\frac{e}{p}\right)_m\right] \cdot \left[1 + \frac{g_s - g_m}{g_s}\right], \quad (25)$$

where H is the altitude between any two pressure levels P_1 and P_2; Z is the corresponding altitude in the standard atmosphere; T_m is the mean temperature of the air column; and T_{m_s} is the mean temperature of the air column in the standard atmosphere used to calibrate the altimeter.

Formula (25) is of general application. If the humidity and gravity terms are neglected, formula (25) becomes

$$H = Z \frac{T_m}{T_{m_s}}. \quad (26)$$

The use of formula (25) or (26) carries the implication that Z is measured with reference to the lower pressure level P_1; the altimeter reading must be corrected to obtain this value of Z or the altimeter adjusted so that it reads zero at pressure P_1.

(*a*) *Isothermal standard atmosphere.*—It is evident that computation of altitude is simplified for standard atmospheres in which T_{m_s} is a constant. For this reason most standard atmospheres used in calibrating surveying altimeters are isothermal; in most such atmospheres the mean temperature is 10°C. = 50°F. = 283 °K. For ease in computation, formula (26) can be written

$$H = Z \left(1 + \frac{T_m - T_{m_s}}{T_{m_s}}\right) \quad (27)$$

where

$$\frac{T_m - T_{m_s}}{T_{m_s}} Z$$

is defined as the temperature correction. Tables of the temperature correction, T_m against Z, such as given in the SMT, can be easily computed and used; nomograms are available for use in calculating H when Z and T_{m_s} are known.

(*b*) *Aeronautic standard atmosphere.*—If the mean temperature T_{m_s} of the standard atmosphere to which the altimeter is calibrated varies, the computation of the temperature correction is more complicated. In the case of the aeronautic standard atmos-

pheres the temperature is assumed to fall linearly with pressure altitude in order to obtain indicated altitudes more nearly in agreement with average atmospheric conditions. Consider only the aviation altimeter calibration standard used in this country; all that will be said will apply equally well to the ICAN standard, or its modifications.

Formula (18c), modified to determine T_{ms} between P_1 and P_2, becomes

$$T_{ms} = \frac{aZ}{\ln \dfrac{288 - aZ_1}{288 - aZ_1 - aZ}} \qquad (28)$$

$$= 288 - aZ_1 - \frac{aZ}{2} \text{ approx.} \qquad (28a)$$

Further, define $288 - aZ/2 = T_{ms}$, whereupon formula (28a) becomes

$$T_{ms} = T_{ms} - aZ_1 \text{ approx.} \qquad (29)$$

where Z_1 = pressure altitude of lower level
Z = altitude between pressure levels P_1 and P_2
a = temperature lapse rate, 0.0019812°C./foot
T_{ms} = standard mean temperature of air column P_1 to P_2
T_{ms} = standard mean temperature corresponding to a pressure altitude equal to Z, easily obtained from available tables.

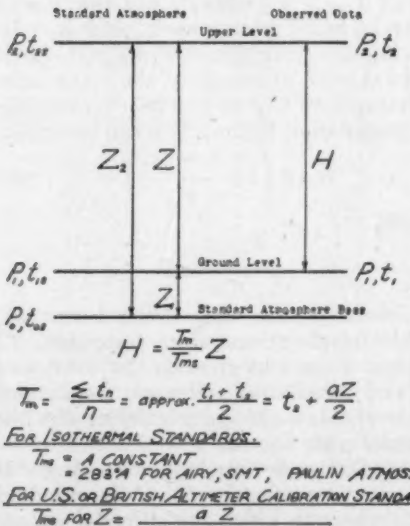

Fig. 3.—Illustrates definitions of terms used in an altitude determination by altimeter.

These definitions are illustrated in Fig. 3.

Formula (28a) or (29) is an approximation with negligible error for values of Z_1 up to 5,000 feet. The error can be found in any individual case by comparing values of T_{ms} computed by formulas (28) and (29).

Thus for aviation altimeters,

$$H = Z \frac{T_m}{T_{ms}} = Z \frac{T_m}{T_{ms} - aZ_1}. \qquad (30)$$

Examples of altitude determination in surveying.—In the following discussion it is assumed that the instruments used are free from error.

(*A*) Accurate elevations of a number of stations in rolling country are to be obtained. It is assumed that there is at least one base in the area or that two bases flank the area, the elevations of which are known; and further, that the time between observations is reasonably short, say, of the order of thirty minutes.

The observations required are as follows:

(*a*) A record must be obtained of air pressure against time at the base or bases. This can be secured most conveniently by a barograph, preferably a microbarograph in order to secure adequate sensitivity.

(*b*) An altimeter, preferably graduated to the altitude-pressure relation of an isothermal atmosphere, is read at the base and at the various selected stations, and recorded, together with the time of observation. It is an advantage from the viewpoint of correcting for drift of the altimeter to repeat the readings in reverse order at each of the points. More consistent results are obtained if the reading is made about 5 to 10 minutes after arriving at the station, particularly if the change in elevation between two stations is relatively great.

(*c*) The air temperature at the base or bases and at each station should be measured at the time of making the pressure observation at each station. A continuous record of the air temperature against time is a desirable means for obtaining the required temperatures at the bases. The ex-

posure of the thermometers must be such as to avoid the direct rays of the sun. The thermometer should be at least 3 or 4 feet above the ground in an effort to measure the true free air temperature. The time of exposure at the station must be sufficient to eliminate the time lag of the particular thermometer used.

(*d*) If the humidity correction is to be applied, the humidity must in general be measured simultaneously with the air pressure under (*b*). If the weather does not change, the water vapor pressure, which is the quantity required, may remain nearly constant from station to station, although the relative humidity will change with temperature.

(*e*) The data for making the gravity correction, if desired, are obtained from published data as previously discussed.

The data in (*a*) are used to secure the value of the base pressure P, or its equivalent the altitude in the standard atmosphere, at the time of making each station observation. This insures simultaneity, but still leaves open the question of verticality of the observations. If observations at two or more bases are available, the base pressure or altitude directly below (or above) the station is secured by interpolation. If there is only one base station, the effect of change in barometric pressure with distance from the base can be determined from a weather map, or pressure data from a nearby Weather Bureau station, or failing these, some estimate can be made from the barograph record at the base.

From data (*a*) and (*b*) the altitude in the standard atmosphere at each station is obtained by simple computation, that is $Z=Z_1-Z_0$, where Z_0 and Z_1 are the altitudes of the base and station respectively.

The mean temperature T_m of the air column may be taken as the mean of the two air temperatures at the base and the station if Z is small, say under 500 feet. In some cases T_m can be taken as the air temperature at the station with little loss in accuracy.

With these data the altitude above the reference base is calculated by formula (26). Further refinement would include humidity measurements to determine the humidity correction (formula 7 or 25) and evaluation of the gravity correction (formula 8 or 25). Then the elevation of the station above sea level is $H+h$, where h is the elevation of the base. With ordinary care an accuracy of 1 percent or about 20 feet, whichever is greater. can be secured.

(*B*) The second example concerns the case where a mountain climb is made and the height of the mountain to the best accuracy is desired. It differs from case (*A*) in that the climb usually requires a relatively long time, extending over one or more days, and in that the base or the point of known elevation is often far from the mountain peak.

As in case (*A*), a pressure and temperature record against time is desirably obtained at a point of known elevation or base.

An altimeter or aneroid barometer, a thermometer, and perhaps a psychrometer should be read at various points during the climb and, of course, at the peak.

The chief difficulty in the computation of the altitude is the adjustment of the temperature data to obtain simultaneity, since the readings at the various elevations during the climb are taken with considerable time interval between them; no hard and fast rules can be laid down, and some uncertainty is inevitable.

No serious error due to failure to obtain simultaneity in the pressure observations made during the climb for use in computing mean temperature will be present if a pressure record is obtained at a base. However, the variation due to distance between the base and the mountain stations or verticality of observations, often requires consideration. In the absence of line squalls and thunder storms, and if the distances between climber and base are not too great, errors due to neglect of verticality corrections in the intermediate pressures used to compute the mean temperature will not introduce serious errors. However, the pressure or altitude reading at the point at which the altitude is to be determined should be corrected for the space factor, if possible, or the correction at least be proved negligible.

Calculations of the humidity and gravity

corrections offer no difficulty since the observed or derived data are not needed to high accuracy and therefore the refinements of applying corrections to obtain simultaneity and verticality can be omitted. The chief difficulty is in making the humidity measurements and, in some cases, in obtaining gravity data.

(*C*) Many exploration trips in unsettled mountainous country are made in which observations of an aneroid barometer or altimeter are the sole reliance for determining altitude. In the extreme case there is no base of known elevation which can be visited except perhaps at the start and finish of the trip. Errors in altitude determination are likely to be quite large owing to variations in the base pressure, which must be implicitly or explicitly assumed, and to a lesser degree owing to the lack of knowledge of the mean temperature. It is best in these cases to use an aneroid barometer which measures the atmospheric pressure, or an altimeter set to read pressure altitude, that is, altitude above the base pressure assumed in the altimeter calibration standard.

Errors due to lack of a base pressure can be reduced somewhat when it is possible to spend a long time at the station. In this case the altimeter or aneroid barometer is read three or four times daily at the same hours as widely spaced as possible. The altitude is then the average of the altitude readings or the average of the pressures converted to altitude in the standard atmosphere, preferably isothermal. This procedure still leaves uncertainty since it assumes a sea level pressure of 760 mm of mercury, while the average sea level pressure at a given station may differ considerably from this value.

In general, altitudes determined by the above procedure give altitudes in winter which are much too low; in summer also too low, but much less so than in winter. Detailed meteorological studies of a given region are required to determine empirical methods of making corrections.

(*D*) A case of general interest is that where altitude observations are made only with an altimeter or aneroid barometer, but readings are secured occasionally at points of known elevation. Here the altitudes of subsequent points of interest are obtained from readings of the instrument, corrected either by adjustment of the instrument to read the altitude of the bases as encountered or by computation to tie in with the points of known elevation. The error due to time from the base will usually not exceed about 50 feet per hour and that due to distance, usually not more than about 50 feet per 10 miles of distance.

The failure to correct for mean temperature of the air column introduces much less error than the above uncertainties, especially when the elevation of the base is a good fraction of the elevation of the point of interest, since the correction is applied only to the observed altitude above or below the base. In general, failure to correct for air temperature error introduces approximately a 1 percent error in the altitude above the base, for every 3°C. deviation in actual mean temperature from the value in the standard atmosphere.

Altitude of aircraft.—When it is remembered that the aneroid altimeter indicates only the altitude between two pressure levels, it is obvious that the altitude of an aircraft above ground level can be determined only in special cases. The changing elevation of the ground below and inability in general to obtain ground level pressure preclude obtaining precise altitude data at all times during flight. Other means than the aneroid altimeter must be used.

However, on airways the ground level pressures at the nearest airport are furnished at close time intervals and knowledge of the airway topography makes it unnecessary in most cases to have more than the altimeter indication For landing, precise indications of altitude above the field can be obtained as discussed later.

The altimeter is particularly useful in flying at a desired pressure level as indicated in terms of pressure altitude, or as is more general, in standard altitude above sea level, approximately. In the latter case the pressure scale of the altimeter is set to the pressure corresponding to the pressure altitude of a nearby airport minus the elevation of the airport above sea level.

There are four cases of particular interest which will be discussed in some detail be-

low. As before, the instrumental corrections will be assumed applied.

A. Airplane flights for an altitude record are made within a few hours usually with take-off and landing from the same airport. Balloon flights take longer and the landing point is usually distant from the take-off point. These flights are all made under the regulations of the Fédération Aéronautique International (*14*). The data obtained are (*a*) pressure and air temperature at the ground level during the flight, (*b*) free air pressure continuously recorded in the aircraft, and (*c*) free air temperature with the corresponding air pressure recorded in the aircraft at short time intervals.

From these data the mean temperature can be computed by the first method described in the section on "Computation of Mean Temperature." It may be necessary to correct the observed values of temperature at the lower levels to obtain observations synchronized with those obtained at the highest altitude.

The altitude is determined officially by a step method, formula 3a, or alternatively by the relation

$$H = 18400 \frac{T_m}{273} L \log \frac{P_0}{P} + A + h, \qquad (31)$$

where H = the altitude above sea level in meters.

T_m = the mean temperature in °K

P_0, P = simultaneous values of the pressure at the ground and at the highest altitude, respectively

L = factor, correcting in terms of latitude for deviation from standard gravity, here 980.62 cm/sec².

A = correction term for variation of gravity with altitude and to adjust for the assumption of a relative humidity of 60 percent. It varies with altitude.

h = altitude above sea level of airport, in meters.

B. The second case, on determining altitude just before landing, is important in ordinary aircraft operation. The problem is to obtain altitude indications sufficiently reliable for use in making a landing. Since the temperature error is zero at zero altitude and indicated altitudes above the airport are sufficiently accurate to clear obstacles at most airports, correction for air temperature error is unnecessary. Thus the problem resolves itself only to that of properly resetting the zero of the altimeter.

Two methods of resetting just before landing are used. In the method usually preferred on airlines, approximate altitude above sea level is indicated because of its advantages in flying over mountainous country. The pressure scale of the altimeter is reset in flight, so that the altimeter will read upon landing the elevation above sea level of the airport. This pressure is officially called the "altimeter setting" and in the early days of its use "the Kollsman Number." This pressure can be obtained at the airport by reading the pressure scale of an altimeter when it is set so that the pointers indicate its elevation above sea level. If only the air pressure is measured at the airport, the "altimeter setting" is determined as follows: Convert the air pressure to pressure altitude, subtract the elevation above sea level of the barometer from the pressure altitude, and finally convert the last obtained altitude to pressure in the standard atmosphere. The "altimeter setting" can also be obtained directly from an aneroid instrument called an altimeter setting indicator, to be described later.

The second method of setting the altimeter in flight is such that the altimeter reads zero upon landing. In this case the pressure scale is reset simply to the ground level pressure received by radio from the airport. This is the reading of the pressure scale of an altimeter set to read zero altitude at the runway level of the airport.

C. For some purposes it is desired to determine the aircraft altitude when above a point of known elevation. The uncertainties in a determination are ordinarily such that consideration of correction factors other than ground leyel pressure or air temperature error is of no significance.

If there is communication with the ground, the altimeter can be set to ground level pressure as indicated in the second method of section B just above; if there is no such contact, the pressure to which to

set the altimeter offers difficulties. It may be preset using a prediction based on a weather map obtained before flight, or by flying low just before the altitude is needed, estimating the altitude, and resetting the altimeter to indicate this altitude. The latter procedure is, of course, not practical if there is ground fog.

In practice, it is not always possible to obtain sufficient data to compute accurately the mean temperature; in fact, only one reading is often available, the free air temperature at the flight level. In the latter case formula (5) is used to compute the mean temperature. The altitude is then computed using formula (26). Computers (*15*) (*16*) are available for computing the altitude based on formula (26) entering either with the mean temperature or with the flight level air temperature.

D. In the last case to be considered flight is to be maintained for some time at a fixed and constant altitude above a base. In this case it is preferable to use an altimeter rather than an aneroid barometer, and one calibrated to an isothermal atmosphere, if there is any choice. The indication of the altimeter to be maintained in flight corresponding to the desired altitude is to be determined.

First, the pressure scale of the altimeter must be kept continuously set to the ground level pressure at the base. Altitudes in the standard atmosphere above the base are then indicated.

The altimeter reading Z corrected for air temperature for the desired altitude H is

$$Z = \frac{T_{m_s}}{T_m} H = \left(1 + \frac{T_{m_s} - T_m}{T_m}\right) H. \qquad (26)$$

The value of Z can be obtained from a curve or a table based on formula (26).

If the mean temperature T_{m_s} in the standard atmosphere is a constant, the computation is quite simple. For example, if $T_{m_s} = 283°K$, the readings to maintain 10,000 feet true are given in Table 3.

If T_{m_s} is not constant, the table becomes more complicated, since T_{m_s} varies with the ground level air pressure. For example, if an altimeter calibrated to the U. S. standard atmosphere is used, it can be shown that

TABLE 3.—ALTIMETER READING TO MAINTAIN 10,000 FEET

Mean Temperature	Altimeter Reading, Z
T_m °C.	Feet
20	9,659
10	10,000
0	10,366
−10	10,760
−20	11,186

T_{m_s} is to a close approximation:

$$T_{m_s} = T_{m_s} + \frac{a(T_m - T_{m_s})H}{2T_m} - aZ_0 \qquad (32)$$

where T_{m_s} = mean temperature in °K obtained by entering tables of mean temperature against pressure altitude with the altitude H

a = temperature lapse rate, 1.98°C per 1,000 feet

Z_0 = pressure altitude at ground level.

The standard mean temperatures for a true altitude of 10,000 feet for various actual mean temperatures, computed by formula (32), are given as an example in Table 4.

TABLE 4.—MEAN TEMPERATURES IN U. S. STANDARD ATMOSPHERE AT 10,000 FEET

Mean Temperature, T_m	Mean temperatures in U. S. standard atmosphere at 10,000 feet true altitude Ground level pressure, inches of mercury				
°C.	29.00	29.50	30.00	30.50	31.00
20	+3.9	+4.8	+5.7	+6.7	+7.6
10	+3.5	+4.4	+5.3	+6.3	+7.2
0	+3.1	+4.0	+4.9	+5.9	+6.8
−10	+2.7	+3.6	+4.5	+5.5	+6.4
−20	+2.3	+3.2	+4.1	+5.1	+6.0

The altimeter readings to maintain 10,000 feet, using the standard mean temperatures in Table 4 and formula (26) are given in Table 5.

TABLE 5.—ALTIMETER READING TO MAINTAIN 10,000 FEET

Mean Temperature T_m	Altimeter reading, feet Ground level pressure, inches of mercury				
°C.	29.00	29.50	30.00	30.50	31.00
20	9,450	9,481	9,513	9,546	9,577
10	9,779	9,802	9,834	9,869	9,901
0	10,113	10,141	10,179	10,216	10,249
−10	10,483	10,517	10,551	10,590	10,624
−20	10,890	10,919	10,954	11,000	11,028

Similar tables, or curves, can be prepared for other desired altitudes.

If gravity or humidity corrections are to be applied, use formulas 7, 8, and 9 and apply the corrections with the opposite sign to the readings of Z given in Table 5 or similar tables.

ANEROID BAROMETERS AND ALTIMETERS

This section will be limited to a brief description and a discussion of the performance of aneroid instruments. Thermometers will not be discussed, since data on the common mercury type ordinarily used in surveying are readily available. See references (*4*) and (*17*) for data on electrical types suitable for aircraft use.

Aneroid barometers and altimeters for convenience may be divided into groups according to function:

(*a*) Aneroid barometers for measuring atmospheric pressure.
(*b*) Surveying altimeters and barometers for determining the elevation of terrestrial points.
(*c*) Aviation altimeters.
(*d*) Altimeter setting indicators.
(*e*) Barographs for recording ambient atmospheric pressure.
(*f*) Aviation barographs.

The development of the aneroid barometer for measuring atmospheric pressure and for use in surveying into an instrument of high precision and reliability has been greatly retarded by the small market for such instruments. Competitive development that accelerates progress has not been stimulated by the available market. However, since the aviation altimeter and the aneroid barometer in their essentials differ very little, the greater emphasis placed on research and development of aviation altimeters has been of immediate benefit in improving aneroid barometers.

The chief aims in development have been (*a*) to increase the sensitivity of indication and coupled with this, (*b*) to make the reliability and accuracy commensurate with the sensitivity. The necessity of portability, since that is the chief virtue of the aneroid barometer in comparison with the mercurial barometer, has focused attention upon methods of protecting the mechanism from shocks normal to transportation.

(*a*) *Aneroid barometers.*—A variety of aneroid barometer mechanisms have been designed and constructed in recent years in efforts to improve over-all performance in the ranges required for measuring atmospheric pressure at weather stations. Among these may be mentioned the Paulin, Friez, Kollsman, and the Wallace and Tiernan. The dial diameter of these instruments

Fig. 4.—Aneroid barometer, range 610 to 1,085 millibars. Pointer makes two revolutions; scale 7½ inches in diameter. The humidity and correction factor is obtained from the nomogram at the top of the cover; the conversion of pressure to altitude in the SMT standard atmosphere is given in the chart in the middle; and data on the temperature error of the barometer can be plotted on the graph at the bottom.

varies from 5 to 9 inches. The pointer may rotate from 270° to several revolutions in the various designs.

In the most open scale of these instruments, the scale length is about 7 inches for each inch of mercury, so that readings to the nearest 0.1 mb or millimeter are easily made. The reliability over a period of

months when in the laboratory appears to be about equal to the sensitivity above given.

(*b*) *Surveying altimeters and barometers.*—Except for an extension in range, and in some cases calibration to a standard atmosphere, usually isothermal, the instruments commercially available are the same as the aneroid barometers discussed under (*a*). At present precision instruments of this type appear to be produced in this country only by Wallace and Tiernan (*18*), although the precision Short and Mason and the Paulin instruments also available in this country should be mentioned.

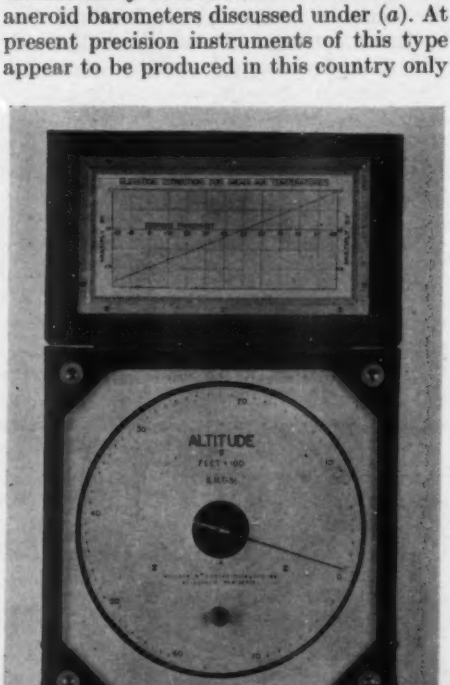

Fig. 5.—Surveying altimeter, −1,000 to 6,000 feet, calibrated to SMT standard atmosphere. Secale, 7½ inches in diameter. Note the chart for determining the temperature correction.

Fig. 4 shows an aneroid barometer for use in surveying in which the chart is used for converting the pressure to standard altitude and for obtaining a factor based on observed air temperatures and relative humidity for use in making a correction for deviation of these quantities from the standard values.

A surveying altimeter is shown in Fig. 5 together with a nomogram for computing the temperature correction when the needed air temperature data are available. The scale, 7½ inches in diameter, covers a range of 7,000 feet in nearly one revolution. It can be read to about the nearest two feet.

Surveying barometers are often equipped with an altitude scale, rotatable with reference to the fixed dial graduated in pressure units. This enables altitude readings to be made in terms of approximate standard altitude above the pressure level of the base.

It should be mentioned that the standard size aviation sensitive altimeter can be read to the nearest one or two feet, but owing to the friction in its mechanism, the reading can not be relied upon closer than about 10 to 20 feet. It is, therefore, not used if more accurate data are required.

However, sensitive altimeters in the 6-inch dial size have been built in which the friction is but slightly greater than that of the surveying instruments above mentioned. These have been used in surveying, although not ideally suited for the work, since none are available calibrated to an isothermal standard atmosphere.

(*c*) *Aviation altimeters.*—A dial view is shown in Fig. 6 of the standard aircraft sensitive altimeter. The major divisions on the dial, 1, 2, etc., have three values: 100 feet for the largest pointer, 1,000 feet for the intermediate pointer, and 10,000 feet for the smallest pointer. The zero adjustment, which has been previously discussed but not described, is made by the thumb knob at the lower left of the instrument. Operation of this knob rotates the inset pressure dial, graduated in inches of mercury, to any desired value in its range; at the same time the pointers are also reset by a corresponding amount. For example, if the pressure setting is reset to 30.00, the pointers are at the same time reset from the reading shown, 411 feet to 484 feet. If the altimeter is now subjected to a pressure of 30.00 inches of mercury, it will read 0 feet. As shown in the figure, the altimeter will read 0 feet at 29.92 inches of mercury, and −73 feet at 30.00 inches of mercury.

On the other hand, if the altimeter is reset to read zero, the pressure indication should

be the ambient atmospheric pressure, or 29.48 inches of mercury, corresponding to the pressure altitude of 411 feet.

For additional details on design and operation see reference (*19*).

(*d*) *Altimeter setting indicators.*—These instruments, described by Colvin (*20*), are essentially altimeters, that is, with a pointer motion directly proportional to altitude, but with a scale graduated in terms of "altimeter setting" commonly 31 to 28 inches of mercury. Their function is to indicate the altimeter setting directly, without the necessity of making the computations necessary when pressure readings are made. The accuracy required is better than can be secured with an aircraft altimeter of the standard sensitive type. Colvin as a result of preliminary tests, shows that the over-all errors should not exceed about 0.01 inch of mercury.

(*e*) *Barographs* for measuring atmospheric pressure will not be discussed except to point out that seasoned microbarographs may be preferable to an aneroid barometer for measuring air pressures at a base, if an over-all accuracy and sensitivity of reading of 0.01 inch of mercury or less is required. Microbarographs commonly available (Friez or Taylor) have a pen motion of 2.5 inches per inch of mercury.

(*f*) *Aviation barographs* commonly used are of the "double traverse" type, that is, the pen makes two traverses of the chart for the range. This instrument is described by Peterson (*21*).

Performance of aneroid barometers and altimeters.—The factors affecting the performance of aneroid intruments are (*a*) hysteresis, (*b*) drift, (*c*) scale errors, (*d*) temperature errors, (*e*) zero shift, (*f*) vibration and friction, and (*g*) shock resistance.

In the discussion that follows, a "rested" instruments is one which has for all practical purposes been subjected to no pressure change in the previous 24 or more hours. An instrument is put into the "cyclic" state by seasoning or subjecting it to a number (not less than about 5) of cycles of pressure change, the range of which defines the pressures for which the cyclic state exists.

All aneroid pressure measuring instruments are subject to errors due to the departure from perfect elastic behavior which is common to all stressed metals. These errors depend on the entire past history of the instrument in a complicated fashion but may be divided roughly as follows: hysteresis, which depends on the direction and magnitude of the last significant stress change, but shows little or no time dependence; recoverable drift, which depends on the stress change and time; and zero shift or irrecoverable drift, which may continue over a long period of time. In general

Fig. 6.—Aviation altimeter. Operating the thumb knob at the lower left resets the pressure scale and correspondingly the pointers. Dial size, 2¾ inches.

the pressure sensitive element contributes by far the most to these elastic phenomena, but all stressed parts are involved to some extent. The friction and other imperfections of the mechanism may contribute to the hysteresis and in many designs may mask it by the uncertainty produced in the readings.

Hysteresis is the difference in reading at a given pressure for pressures decreasing and increasing when the instrument is subject to a pressure cycle. In general the change in reading in each half of the cycle tends to lag behind the pressure. Thus an altimeter reads higher at a given pressure in the altitude-decreasing (pressure-increas-

ing) than in the altitude-increasing part of the cycle.

The hysteresis is in general a maximum at approximately the middle of the pressure range of the cycle.

The hysteresis at ambient atmospheric pressure, that is, at zero altitude at which the pressure cycle usually is started, is sometimes referred to as the after effect. The recovery or the return to the initial reading obtaining before the pressure cycle requires 24 hours or more.

If the instrument is in the cyclic state in subsequent cycles made within an hour or so afterwards, the hysteresis is reduced to about 50 per cent in amount and the after effect to about 25 per cent or less. The hysteresis for the cyclic state is largely the component independent of time. The other component, which is a time phenomena, is recoverable drift, as discussed later.

The hysteresis is affected somewhat by the speed of making the pressure cycle, but in most circumstances not significantly.

In the best altimeters and aneroid barometers now available the hysteresis of a rested instrument, when subjected to a pressure cycle in which the pressure altitude is changed approximately uniformly at a rate between 200 to 500 feet per minute, is about as follows:

	Altitude and pressure range of cycle			
	0–2,000	0–10,000	0–15,000	0–35,000 feet
	760–700	760–500	760–400	760–200 mm Hg
Maximum hysteresis:				
in feet....	5–10	10–20	20–35	40–70
in per cent pressure change..	—	0.10–.20	.15–.25	.15–.25
Initial after effect, feet.	2–5	7–15	—	40–60

In cycles of small pressure range, the uncertainty in reading is more likely to be of greater magnitude than the hysteresis.

Drift is the slow and usually small change in reading with time subsequent to any and every pressure change. To illustrate, if an aneroid barometer or altimeter be suddenly subjected to a pressure change, the reading will change an amount approximating the pressure change within a few seconds and then will continue to increase slowly for hours in the direction of the pressure change. The rate of drift is greatest initially and decreases quite rapidly with time. If the sensitivity of the instrument is sufficient the increases in reading may be detectable for a time interval after the pressure change up to 24 hours or more.

Drift occurs in all instruments, the sensitive element of which is an elastic system, as for example, a spring or a diaphragm capsule.

The observed drift is the resultant of the effect of all pressure changes that have been imposed upon the instrument up to at least 24 hours previously; the magnitude of the contribution is greatest for larger pressure changes and for pressure changes imposed most recently. In other words, the reading of the instrument depends upon the history of the pressure changes to which it has been subjected. It is therefore impractical to apply corrections for drift except perhaps for the simplest conditions of use.

The relatively small amount of dependable data available indicates that in good quality aneroid instruments originally in the rested state, the drift in one hour, observed after a sudden change in pressure with the initial reading obtained in about one minute after completing the pressure change, is of the order of 0.15 percent of the pressure change; if the rate of pressure change is equivalent to about 1,000 feet per minute the drift reduces to about 0.10 percent. The rate of drift is most rapid initially; about one-half of the drift occurs in the first 30 minutes. For examples of drift curves see reference (*19*).

The initial after effect, after completing a pressure cycle made as rapidly as possible except for a 2-hour drift period at the lowest pressure, for good quality altimeters originally in the rested state, varies from about 0.2 to 0.3 percent of the pressure change. The amount is somewhat less if there is no drift period; for values see the section on hysteresis. The initial after effect in general is somewhat less, if the pressure cycle is made relatively slowly, particularly in the part of the cycle near the initial pressure. In this case some of the recovery has had time to take place before reaching the initial pressure.

Drift is of particular importance in determining the altitude of aircraft in landing.

Subsequent to the landing the drift continues for a time interval up to 24 hours or more, independent of the length of time at altitude. This drift at the end of a pressure cycle is often called "recovery"; the amount by which the altimeter fails to indicate upon landing the reading before the flight at the same pressure is called the "after effect." The altimeter reading upon landing is always higher than the reading at take-off, making due allowance for the difference in the take-off and landing pressures. The recovery becomes larger with time, the after effect, smaller.

If the instrument is in the cyclic state for a given pressure range, the observed after effect just at the completion of the pressure cycle will be much reduced. In this case readings are being compared which are both unstable with time; recovery to the "rested" condition is taking place with time when the instrument is in the cyclic state.

Scale error, sometimes called calibration error, is the error in the indication of the instrument, usually determined when the instrument is at a specified temperature in the range 20 to 25°C. It is a measure of the accuracy to which the correspondence of dial to mechanism performance has been achieved. In most designs adjustments are provided in the mechanism to obtain this correspondence within close limits. The scale error, E, is related to the reading R and true value T by the relation $R=T+E$; thus a plus error means that the instrument reads too high, a minus error, too low.

It is often more convenient to have the corrections to be applied to the readings. In this case the correction C is defined as follows: $T=R+C$.

In many cases the scale error is the only error for which it is practical to apply correction to instrument readings. This is particularly true of aneroid barometers and altimeters. If corrections will be applied, the amount of the scale error is not important, although it is distinctly advantageous that it be as small as possible. The scale errors of an altimeter, unless otherwise specified, are for the case when the pressure scale is set to the value at zero feet, so that the altimeter should indicate pressure altitude in the particular standard atmosphere to which it is calibrated. For other pressure settings the scale error at a given indication may be expected to differ.

Because of drift, the scale error of precision instruments is affected significantly by the average rate at which the pressure is changed during the course of a test. The practice in testing is to change the pressure to which instruments are subjected by steps; at each step the instrument and the standard are read. The average rate of pressure change is governed largely by the time at each pressure step. For altimeters the reading is made in from about 2 to 10 minutes after the pressure change has been made without obtaining significant differences in scale error. For barometers and altimeters not used in aircraft it is usually desirable that the reading be made as long a time as possible after completing a pressure change in order to obtain corrections under conditions most closely simulating service conditions; twenty minutes between test points seems a practical limit in routine testing.

For general use, where the direction and rate of the pressure changes can not be definitely specified, it is best to take as the scale error at a given reading, the average of the error for pressures decreasing and increasing obtained in a pressure cycle. Whenever the conditions of use can be simply specified as in case of readings made during steady continuous ascent of an airplane, the corrections for the errors under these conditions should be applied. However, even the slightest reversal of pressure change will make the error uncertain to some degree.

Altimeters used as secondary standards will have much less spread in their errors at a given reading due to drift and hysteresis if they are originally tested and only used when in the cyclic state. This state is obtained by subjecting them to about five pressure cycles covering their range. Since the altimeter gradually returns to the rested state, the procedure should be repeated if the time between the above procedure and use is much longer than about an hour.

It has not up to the present been practical to apply corrections to aneroid instruments for drift and hysteresis under the varied conditions of service use. In simple cases,

such as an aircraft flight up to an altitude, in which a pressure-time record is obtained on a barograph or otherwise, the instrument can be calibrated under the same flight conditions of temperature, pressure and time reproduced in the laboratory. This is known as a flight history test.

(*d*) *Temperature errors* are the effect of variation in instrument temperature upon the scale errors. The drift and hysteresis are not affected by instrument temperature in any practical amount. In uncompensated instruments the effect of temperature is a maximum at the highest pressure of the range, because the deflection of the pressure element is then greatest. Commonly, in short-range instruments the temperature compensation is such that it is perfect at one pressure only, but in view of the short range, the compensation is sufficiently perfect at other pressures. In long-range instruments, as aviation altimeters, compensation for all readings over the entire range of pressure is desired, which is not as easily accomplished. The latter is often called "range compensation."

The compensation can be made practically perfect but at considerable extra expense because each instrument requires adjustments and tests to achieve it. In practice, tolerances for the temperature error are allowed. Corrections for the error determined by appropriate tests can be applied, although special precautions must be taken in measuring the instrument temperature because of its time lag in following ambient air temperature.

(*e*) *Zero shift*, sometimes called secular error or zero drift, is a change in the whole scale error curve which occurs slowly with time at atmospheric pressure and temperature, but may be accelerated by pressure and temperature cycles. There is no recovery. It usually manifests itself as a pointer motion in the direction of increasing pressure. Its irreversibility, or failure to recover, distinguishes it from the drift previously considered It appears to be caused primarily by the release of trapped fiber stresses in pressure elements which are in the cold-worked condition. The pressure element can be stabilized in this respect by artificial aging or seasoning, which is accomplished by subjecting it or the complete instrument to a combination of pressure and temperature cycles. Particularly effective is an exposure for a short time to a temperature just short of that which will remove the hardening effect of cold work.

Unless accelerated, the zero shift may continue for several years, but at a diminishing rate.

A zero shift, but with an opposite direction of pointer travel, will occur if the diaphragm capsule leaks. Obviously the instrument is unusable in this case. Wear in the bearings of the mechanism, often as a result of rough handling of the instrument, may also cause a zero shift.

(*f*) *Vibration and friction* are especially important in the sensitive aviation altimeter now available. The friction is of the order of 100 feet, but is removed, with a residual uncertainty of about 10 feet by a vibration with an amplitude of about 0.001 inch. Since vibration of considerable amplitude may damage the altimeter, inevitably so if at the natural frequency of the mechanism, the vibration to which it is subjected is controlled by installing the instrument board upon which it is mounted in vibration-absorbing mounts.

Other aneroid instruments are available which are remarkably free from friction. However, it is on the safe side to tap all aneroid instruments slightly to insure a friction-free reading. Instead of tapping, operation of a small bell buzzer attached to the instrument may be preferable in the case of instruments with much friction, in view of the uniformity and relatively high frequency of the vibration thus obtained.

In general, installations in which the aneroid instruments are subjected to severe vibration should be avoided, especially so if there results any sensible pointer vibration.

(*g*) *Shocks* to aneroid instruments lead to damage to the delicate pivots and bearings of high quality instruments. Breakage of the parts may occur. On this account the instruments require protection during shipment. In the field use of surveying aneroid the practice seems to be growing of requiring that shock protection be incorporated inside of the instrument case. The requirement that surveying instruments be rugged

appears to be essential in view of conditions of use in the field.

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ANTHROPOLOGY.—*The De Luna Expedition and the "buzzard cult" in the Southeast.*[1] JAMES B. GRIFFIN, University of Michigan. (Communicated by JOHN R. SWANTON.)

For a great many years American archeologists have been puzzled by a series of resemblances between the Southeastern United States Middle Mississippi cultures and those of the Mexican area, and a considerable amount of time and speculation has been devoted to either explaining the relationship or explaining it away. (Holmes, 1883, was one of the best early studies.) Prominent among these connections has been a series of drawings of dancing figures and other anthropomorphic concepts, placed on shell and pottery, and figures cut out and impressed in copper. By some students these were interpreted as direct Mexican influence that came into the Southeast as the result of a migration (Radin, 1927, pp. 192–202; Nuttall, 1932, pp. 137–144) and produced the Middle Mississippi culture. Others considered these art styles to be the result of some inherent quality in the Indian mind which at a given cultural level would produce similar "Indian art" styles

[1] Read before Society for American Archeology, Washington, May 13, 1944. Received May 20, 1944.

(Thruston, 1890, chap. 9). Others interpreted the Mexicanlike artifacts as objects fabricated in the Southeast by a small group of Mexican exiles. No one suggested that the items were made in Mexico. Willoughby (1932, p. 45) maintained that the designs and craftsmanship, particularly on the copper plates, is Muskhogean and not Mexican, and Phillips reiterated the opinion that the plates did not resemble any known contemporary Mexican work.[2] With regard to the general Mexican resemblances, and particularly the shell gorgets, Phillips said, "To account for this tendency without some sort of contact involves a terrific strain on the theory of 'psychic unity.'"[3] Phillips also recognized, as have others, that the Mexicanlike material was spread like a thin wash in the Southeast and was certainly not part of the "original" Middle Mississippi, whatever and whenever that might have been.

Some students have viewed these art styles as the expression of a religious revival brought about during a fanciful period of decline and decay of southeastern culture (Ford and Willey, 1941, pp. 357–359). In the writer's opinion the art styles resembling Mexican forms are a part of the culture at the highest aboriginal level of accomplishment and represent not a stage of retrogression but the Southeast at its apogee.

The recent archeological activity in the Southeast has demonstrated rather clearly that this particular cultural manifestation is almost certainly post-De Soto (1540) and belongs to a period only shortly before the coming of the French and English traders into the Southeast. During the Third Round Table Conference in Mexico City in 1943, I discussed this art style with Mexican anthropologists, who recognized it as having close relationship to the art forms of the Mixteca-Puebla Culture, which were contemporary with the Conquistadores (Vaillant, 1940, pp. 209–305; comments by Dr. Caso in Mexico City, September, 1943; Ekholm, 1944). In other words, we are dealing with approximately contemporary art manifestations.

[2] This opinion is largely negated in Moore, 1905, pp. 225–227.

[3] Phillips, 1940, p. 356. This is essentially Holmes's position and was seconded by Starr, 1897.

Some individuals had suggested that De Soto might have taken mercenaries or camp followers from Mexico to the Southeast, but there is no record or suggestion that he did so. However, we do have record of another expedition into the Southeast, which may contain an explanation for this interareal connection. In 1559 Tristan de Luna led an expedition to the Gulf coast which was organized in Mexico City for the purpose of establishing a Spanish base on the Gulf coast and on the southeast Atlantic coast to forestall the encroachment into the area of other European powers.[4]

The armed force or striking power of the expedition was furnished by Spaniards from Mexico City, Oaxaca, Los Zacatecas, and Puebla. It is possible that the Spanish soldiers and officers from these areas had local Indians as their servants and camp followers. The expedition left Mexico City in mid-April and moved to Tlaxcala where it remained until May 12. At this point the Viceroy wrote to de Luna regarding the composition of the expedition:

> They tell me that the *canaille* of halfbreeds, mulattoes, and Indians who are being taken by the people (soldiers) are very numerous; you will find that the great part of these will only serve to set the camp in confusion and eat up the supplies. I think it will be enough to send only as many servants as there are soldiers to go, and only those who are to embark should go down from Halapa. (Priestley, 1928, vol. 1, p. 54.)

The sailing date from San Juan de Ulua was June 11, 1559. The party was composed of 500 soldiers, 1,000 servants and colonists (including women, children, Negroes), a large number of Mexican Indians, and 240 horses. They embarked in 13 ships. Advance knowledge and international considerations had set their goal as the port of Ochuse or Polonza (Pensacola Bay), but they sailed past it to the Bahia Filipina (Mobile Bay). A frigate was dispatched east to locate Ochuse, and after this was accomplished the whole fleet arrived at Ochuse on August 14. Exploring parties were sent out, one of which evidently followed the course of the Escambia River. The area about Pensacola

[4] The account of the expedition in this paper has been extracted and condensed from the following publications: Swanton, 1922, pp. 159, 230–239, 240, 254–256; 1939, pp. 209–218; Lowery, 1901, pp. 351–377; Priestley, 1928, 1936.

was not densely populated nor was the Escambia drainage. While these scouting parties were gone, a hurricane blew for 24 hours on August 19 and wrecked all but three small boats and destroyed most of the supplies. When the exploring parties returned and reported that the land was poor and there were few Indians to support them the expedition was faced with an unpleasant future. Another exploring party of 200 Spaniards and "canaille" was sent to penetrate farther into the interior, and some 40 leagues north they found a temporarily abandoned Indian town of 80 houses, called Nanipacana or Nanipacna, on a great river which is probably the Alabama. It was located close to the site of Mabila or perhaps may have been Mabila itself, since the story told by its inhabitants checks with the history of Mabila, and the distance from Mobile Bay to both towns is very close. Halbert thought that Nanipacana was in Wilcox County, while Lowery and Swanton favor a location in Monroe County. Certainly, no very exact information is given in the accounts of the expedition. The name of this town is said to be a Choctaw word meaning "high mountain or hilltop." In this village the scouting party found maize, beans, and other food that had been left by the Indians, who had fled as this new party of Spaniards approached. In the meantime, two vessels with provisions arrived from New Spain, so that de Luna did not move the majority of his party to Nanipacana until early April, 1560. He left a small party at Ochuse to guard the port. This meant that a motley group of 1,500 persons were attempting to live in an Indian village of 80 houses. On April 15 de Luna sent out a party of about 300 under Mateo de Sauz to visit Coosa. They went toward the northeast and, not finding much food, were reduced to dire straits. The first part of June they found provisions and sent back to de Luna 40 bushels of corn from a town called Caxiti (Casiste, a day's march west of Talisi, located at Durand's Bend). Proceeding up the Alabama they stopped at Onachiqui, one of the first Coosa towns which was near the Olibahali River. They did not stay long but journeyed north to Coosa, which turned out to be a community of 30 houses and 7 suburban centers. This town was located on the east side of the Coosa River in Talladega County, between the mouths of Talladega and Tallaseehatchee Creeks. The majority of the party remained at Coosa for at least three months, and one of their most notable exploits was to aid their hosts in a conflict against the Napochies, who have commonly been identified as living to the west, because of the association of their name with Napissa, an Indian group mentioned as being associated with the Chickasaw by Iberville 140 years later and because of the mistaken idea that the Napochies lived near the Mississippi. However, it was only a few days' march from Coosa to the first Napochie town whose inhabitants had fled to the second Napochie town, which was near a river called Oquechiton. This has been identified as the Mississippi, the Yazoo, the Black Warrior, and the Tennessee. As the name given means "the great water," as Padilla states, some historians have concluded that the party reached the Mississippi. The location of the towns is not known.

Meanwhile, the main group at Nanipacana was slowly starving to death, and during June and July serious differences of opinion arose as to the best course to follow. Of particular interest is the June 23 petition, drawn up by the principal Indians and Indian craftsmen from Mexico, urging de Luna to allow them to return. The petition was ignored. De Luna wanted to march north to join Sauz in Coosa, but the majority of the expedition wanted to go back to Mobile Bay. The move south was effected about June 24, 1560, and a message was placed in an urn which was buried beneath a tree with a message placed on the tree for the returning Coosa party to "dig below." Shortly after the main party arrived in Mobile Bay two ships arrived with additional but insufficient supplies so that women, children, and the sick were allowed to embark for Havana and New Spain. At the command of King Philip of Spain, two boats were dispatched to set up a base near Beaufort, S. C., in order to forestall the French from settling along the southeast coast. The main party moved back to Ochuse, where, in August, they received the

messengers from Sauz who reported that the scouting force was getting along fairly well at Coosa. De Luna wished to take the bulk of the able bodied and set up a base at Coosa, but his men refused to follow him, and from September, 1560, to April, 1561, the remainder of the expedition struggled along in Pensacola Bay while the majority of the group sent to Coosa evidently remained there. De Luna's successor, Villafane, had been ordered to establish the base on the southeast Atlantic coast, and in April 1561, he took with him such members of the De Luna Expedition as still had stomach for pioneering. The official records do not pay much attention to the fate of the Indians taken on the expedition or say how many were left in Alabama, returned to Mexico, or perished in the Southeast.

The Indians had been taken along as "C. B." battalions or engineers to build settlements, repair broken equipment, and to undertake all the disagreeable but fundamental tasks that the Spanish were too busy to do for themselves. De Soto had taken Indian women from Coosa and they spent almost 20 years in Mexico. They returned to Coosa with Sauz's party. Thus, for almost two years there was a large group of Mexican Indians from the specific areas where the most profound resemblances to the southeastern late art styles are located, and they were in an area that is quite close to a heavy concentration of objects attributed to Mexican influence.[5] First of these sites is Moundville located on the Black Warrior River, a short distance south of Tuscaloosa, Ala., and which is fairly close to the probable location of the Napochie towns. The other prominent center of Mexicanlike material is at Etowah in Barlow County, Ga., in the headwaters of the Coosa. Both Moundville and Etowah are believed to belong to the later prehistoric archeological period and have been tentatively dated by archeologists at about 1550–1650. On the basis of the archeological data there is little doubt that they were occupied contemporaneously during at least part of their existence, for some of the pottery from Etowah was almost certainly inspired by or directly derived from Moundville, and pipes of the distinctive late North Georgia style have been found at Moundville. Another center where shell objects, suggesting Mexican origin, have been found is around Montgomery. Another major center for the shell disks is in eastern Tennessee.

There have been some theories about the passage along the gulf coast of migratory groups, either by land or by boat, who then moved up the Mississippi and established a center of Middle Mississippi culture. Some such explanation may later be demonstrated for earlier elements of either Middle Mississippi or Hopewellian, but the distributional features of the buzzard-cult artifacts indicates that there was no significant use of such concepts in Texas, Louisiana, Arkansas, or southern Mississippi. There is one famous site that has a considerable amount of material of this nature, namely, Spiro in the Arkansas Valley of eastern Oklahoma, and that question will be dealt with in another paper.

Unfortunately, European-manufactured objects, or items brought into the Southeast from Mexico, have been rarely identified as of this 1560 period. The sole exception known to me so far is a coin and other non-Indian material found by Moore with a burial under a pottery vessel in a mound at Bear Point in Perdido Bay. This was a Mexican silver coin of the 1525–1550 period (Moore, 1901, pp. 423–432). Since the vessel belongs in the Fort Walton period, some of our ideas about cultural chronology in the lower Southeast may be in for a change, depending upon the date at which the coin was deposited. It would seem reasonable that either at Nanipacana or at Coosa some item of Spanish origin would be associated with Indian artifacts so that cross dating might be effected. Many items of European origin have been recovered in the Montgomery area, but the majority of these are evidently of the 1680–1750 period, and the same holds true for the trade goods in comparable sites on the Tennessee.

[5] Ekholm, 1944, pp. 443–444. The reference to "Etowah" should read Moundville. The resemblances between the skull, heart, and long bones on Moundville vases and those in the Mexican Codices is reported in Moore, 1905. This was not mentioned by Phillips, nor was I aware of it at the Round Table Conference. This resemblance was noted by Caso.

It is, therefore, the purpose of this paper to suggest that the De Luna Expedition might well have furnished the impetus that resulted in the adoption in the southeast of various Mexican art styles and concepts. An intensive and considerable amount of research, however, is needed to analyze and compare the various representations in the Southeast and to examine the Mexican records to see the degree of resemblance to the culture of the area from which the De Luna Expedition in 1559 obtained their Indians.

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PALEONTOLOGY.—*A new fossil comatulid from the Cretaceous of Cundinamarca, Colombia.*[1] AUSTIN H. CLARK, U. S. National Museum.

Dr. José Royo y Gómez, geologist of the Ministerio de Minas y Petroleos, Bogotá, Colombia, with the consent of the Ministry and of Brother Apolinar María, director of the Museo del Instituto La Salle, has kindly submitted to me for study two unusually interesting specimens of a fossil comatulid from the Cretaceous of Colombia. These are the first comatulids to be reported from the Cretaceous in any area outside of Europe. The specimens are unusually complete, with cirri, division series, arms, and fragmentary pinnules; but they do not show the centrodorsal clearly, and the articular faces of the radials are not visible at all. They represent a remarkable new species quite different from any heretofore known, necessitating the creation of a new genus. This new genus finds its closest association with the family Palaeantedonidae, known from the Upper Cretaceous to Quaternary in England, France, Belgium, Holland, Denmark, southern Sweden, northern Germany, Austria, Hungary, Italy, Algeria, and possibly Sinai, Java, and South Carolina.

Some of the species belonging to certain genera of the family Palaeantedonidae might equally well be referred to the recent family Antedonidae, as for instance certain species of *Palaeantedon.* The specimens under consideration, however, although showing many features which would permit their reference to this family, present others, especially the uniformly short pinnule segments and the strong beaded ornamentation

[1] Received April 3, 1944.

of the distal edges of the brachials, that suggest a rather remote relationship to this group.

I am deeply appreciative of the courtesy and generosity of Dr. Royo and of Brother Apolinar María in affording me the opportunity of studying and reporting upon these most interesting specimens. In honor of Dr. Royo I take pleasure in designating the new genus represented by the name of—

Roiometra, n. gen.

Diagnosis.—A genus of the family Palaeantedonidae including large species (with the centrodorsal 12 mm in diameter) with very numerous (over 100 [C]) very slender cirri composed of elongate proximal and short smooth distal segments; 10 arms composed of short oblong, or nearly oblong, brachials, which have the distal edges ornamented with a row of conspicuous beadlike tubercles; the IBr series 2; and flexible pinnules composed of segments which are not longer than broad.

Genotype.—*Roiometra columbiana*, n. sp.

Occurrence.—Cretaceous of Cundinamarca, Colombia.

Roiometra columbiana, n. sp.

Description.—The surface of the centrodorsal is nowhere visible, but from the pattern of the basal segments of the cirri still adhering the centrodorsal appears to be hemispherical or subconical, about 12 mm broad at the base and about 10 mm high. The pattern of the basal cirrus segments indicates that the cirrus sockets are arranged in very numerous closely crowded alternating rows which, from the rim to the dorsal pole, are probably between 12 and 15, or possibly more, in number. From the small size of the basal cirrus segments it is apparent that the cirrus sockets are very small. The indications are that the bare dorsal pole is very small.

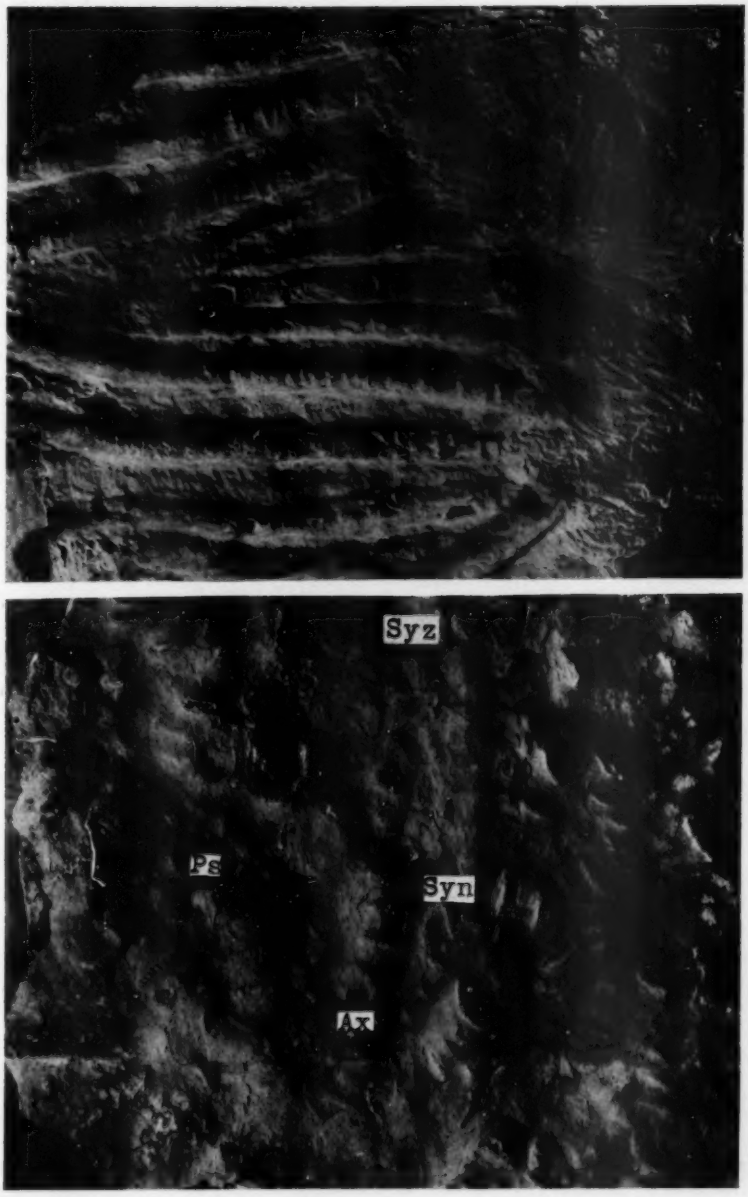
The cirri are exceedingly numerous and very slender, appearing somewhat like a tuft of coarse hair. They are probably well over 100 (C) in number. Most of them appear to be about 27 mm in length, with the longest peripheral cirri about 34 mm and the cirri near the dorsal pole much shorter; the width is from 0.5 to 0.7 mm. They are composed of probably 25–30 segments. In the longest cirri the longest earlier segments are between 3 and 4 times as long as broad, slightly constricted centrally and slightly flaring distally, and the outer segments are from about as long as broad to half again as long as broad with slightly broadened distal ends. The terminal portion of the cirri appears to taper to a point. There are no indications of dorsal or of opposing spines.

The division series and a considerable portion of the arm bases are concealed by the dense mass of cirri. The arms seem to have been 10 in number. They are about 5 mm in diameter, and as far as they are preserved, in one case for 80 mm beyond the cirri, they do not taper. The brachials appear to be between 3 and 4 times as broad as long; the earlier have the ends somewhat oblique, the later have them parallel or nearly so. The distal ends of the earlier brachials are somewhat produced, and from their appearance were either tubercular or spiny. There is no definite evidence of syzygies.

There are many scattered pinnule segments in the matrix between the arms, but most of them are indefinite. They are mostly grouped in short series. From the way in which most of these series are curved it is evident that the pinnules were flexible. Some series of pinnule segments lie across the arms where they simulate a beadlike ornamentation of the brachials. The pinnule segments are all short, none of them being longer than broad. On what appear to be the earlier segments the outer end is produced on the distal side into a high spine. The outer pinnule segments taper proximally to a narrow base.

On the reverse side of the slab, beneath the specimen on the right, a IBr series is visible. The IBr_1 is about 2.5 mm long, and about half again as broad as long; the proximal and distal edges are rather strongly everted and thickened. The IBr_2 (axillary) is about 3.5 mm in length, broader than long, pentagonal, with the lateral borders about two-thirds as long as those of the IBr_1 and making a broadly obtuse angle with them, and the distal edges almost straight and ornamented with a row of 6 or 7 prominent rounded tubercles; the anterior angle measures about 90°.

The first brachial is wedge-shaped, about half again as long exteriorly as interiorly, and about as broad as long in the median line. The distal edge is bordered with a row of tubercles resembling those on the distal edges of the axillaries. The second brachial is less obliquely wedge-shaped, almost oblong though slightly



ROIOMETRA COLUMBIANA, n. sp.

Upper: Two specimens, natural size. *Lower:* Portion of reverse side of slab, beneath the right hand specimen shown above, ×2. Ax = IBr axillary; Ps = pinnule segments; Syn = synarthry; Syz = syzygy. Objects referred to are to the right of the letters, except the synarthry, which is below.

longer exteriorly than interiorly, slightly larger than the first brachial, with the surface slightly concave and the distal border everted and ornamented with a row of about 10 tubercles. As is shown on another arm, the first two brachials are united by synarthry. The third and fourth brachials are united by syzygy, forming a syzygial pair which is somewhat longer than broad; the fourth brachial (epizygal) has the distal edge everted and bordered with a row of tubercles; the distal edge of the third brachial (hypozygal) is unmodified. The right arm is broken off at the distal end of the first syzygial pair. On the left arm the fifth brachial is wedge-shaped, about twice as long exteriorly as interiorly, and short, about three times as broad as the median length. The sixth brachial is similar, but the long and short sides are reversed.

The underside of the slab is almost entirely covered with brachials, mostly in more or less long series, but many as individuals or in small groups. Nearly all these are much worn and so the details can not be made out, though a few are in fairly good condition. Most of the brachials are from 4 to 4.5 mm in diameter, and the outline of the dorsal half is a regular semicircle. The distal edge is everted and somewhat produced, and in the best preserved brachials is tubercular. From the ends of the transverse ridge through which the central canal passes the sides of the brachials converge ventrally in two straight lines making with each other an angle of about 70° to a rather sharply rounded apex; these two converging straight lines are the outer edges of the muscular fossae. Some of the brachials show syzygial faces. These are perfectly developed, with apparently 16–18 radiating ridges.

Together with the brachials there are many pinnule segments, mostly in short series of various lengths, though many are isolated. Some few of these are still in close proximity to the brachials to which originally they were attached. All these pinnule segments are so worn that little can be said about them further than that they are somewhat broader than long, or at least not longer than broad, with more or less constricted proximal ends. A first pinnule segment still attached to a brachial is subtriangular with the apex, adjacent to the brachial, very broadly rounded, slightly broader than long, with a straight distal edge. The pinnule segments are evenly rounded dorsally, and the distal border is usually more or less strongly produced.

Type.—From Naranjillo, Municipio de La Vega, Departamento de Cundinamarca, Colombia; in the Museo del Instituto de La Salle, Bogotá, República de Colombia. From the Middle Villeta formation of the middle Albian, or about middle Cretaceous.

Remarks.—A considerable number of fossil comatulids have been recorded from the Cretaceous of England, Europe, and north Africa. Quite unidentifiable are: *Comatula* sp. Étallon, 1857 (France); *Antedon* sp. Downes, 1880, 1882 (England); *Antedon* sp. Stolley, 1891 (Schleswig Holstein); *Antedon* sp. Jahn, 1895 (Bohemia); *Antedon* sp. Hennig, 1899 (Sweden); and *Eudiocrinus* sp. Brünnich-Nielsen, 1913 (Denmark). Species known only from brachials are: *Antedon granulata* Brünnich-Nielsen, 1913 (Denmark); and *Antedon stevensi* Brünnich-Nielsen, 1913 (Denmark). A species of which the arms are known but the calyx ossicles are only imperfectly described is: *Pachyantedon beyrichi* Jaekel, 1891 (north Germany).

Species in which only the centrodorsal is known are all referred to the genus *Glenotremites* Goldfuss, since their true systematic position cannot be determined. These are: *Glenotremites adregularis* Gislén, 1925 (England); *G. alternata* Gislén, 1925 (England); *G. angelini* Gislén, 1924 (south Sweden); *G. arnaudi* de Loriol, 1894 (south France); *G. bathëri* Gislén, 1924 (England); *G. concavus* Schlüter, 1878 (Holland); *G. discoidalis* Gislén, 1925 (Bohemia; Belgium); *G. essenensis* Schlüter, 1878 (west Germany); *G. e.* var. *tuberculatus* Gislén, 1925 (England); *G. excavatus* Gislén, 1925 (England); *G. exilis* de Loriol, 1869 (Switzerland); *G. faxensis* Brünnich-Nielsen, 1913 (Denmark); *G. intermedius* Gislén, 1925 (England); *G. janeti* Valette 1917 (France); *G. laticirrus* P. H. Carpenter, 1880 (England); *G. lettensis* Schlüter, 1878 (west Germany); *G. lundgreni* P. H. Carpenter, 1880 (England); *G. minutissimus* Valette, 1917 (France); *G. paradoxus* Goldfuss, 1831 (north and west Germany; Belgium, England); *G. parvicavus* Gislén, 1924 (Denmark); *G. parvistellatus* Gislén, 1925 (England); *G. parvus* Gislén, 1925 (England); *G. perforatus* P. H. Carpenter, 1880 (England); *G. pusillus* Fritsch, 1910 (Bohemia); *G. pyropa* Zahalka, 1892 (Bohemia);

G. rosaceus Geinitz, 1871 (Bohemia; ?Saxony); *G. rotundus* P. H. Carpenter, 1880 (England); *G. rogosus* P. H. Carpenter, 1880 (England); *G. schlueterianus* Geinitz, 1871 (Saxony); *G. scutatus* Gislén, 1925 (north Germany); *G. semiglobularis* Brünnich-Nielsen, 1913 (Denmark); *G. striatus* P. H. Carpenter, 1880 (England); *G. sulcatus* Schlüter, 1878 (south Sweden); *G. tourtiae* Schlüter, 1878 (west Germany); and *G. valetti* Gislén, 1924 (France; England).

Specimens in which at least the centrodorsal and the basal and radial rings are preserved are capable of more exact systematic allocation. As determined by Prof. Torsten Gislén these fall in the following families and genera: Family COMASTERIDAE: *Palaeocomaster lovéni* P.H. Carpenter, 1880 (England). Family SOLANOCRINIDAE: *Solanocrinus almerai* de Loriol, 1900 (Spain); *S. campichei* de Loriol, 1879 (Switzerland); *S. gevreyi* de Loriol, 1902 (France); *S. gillieroni* de Loriol, 1879 (Switzerland); *S. hiselyi* de Loriol, 1869 (Switzerland); *S. humilis* Gislén, 1924 (France); *S. infracretaceus* Ooster, 1871 (Switzerland); *S. leenhardti* de Loriol, 1908 (France); *S. picteti* de Loriol, 1879 (Switzerland); *S. ricordeanus* d'Orbigny, 1850 (France); *S. vagnacensis* de Loriol, 1888 (France); and *S. valdensis* de Loriol, 1868 (Switzerland). Family CONOMETRIDAE: *Amphorometra alta* Gislén, 1925 (England); *A. brydonei* Gislén, 1924 (England); *A. conoidea* Goldfuss, 1839 (north Germany; Holland); *A. c.* var. *laevis* Gislén, 1924; *A. c.* var. *granulata* Gislén, 1924; *Placometra mortenseni* Gislén, 1924 (England); *Jaekelometra belgica* Jaekel, 1901 (Holland); *J. columnaris* Gislén, 1924 (Holland); and *Conometra rugiana* Gislén, 1924 (north Germany). Family NOTOCRINIDAE: *Loriolometra retzii* Lundgren, 1874 (Sweden); *Sphaerometra aequimarginata* P. H. Carpenter, 1880 (England); *S. carentonensis* de Loriol, 1894 (France); *S. incurva* P. H. Carpenter, 1880 (England); *S. semiglobosa* Schlüter, 1878 (Germany); *S. senonica* Gislén, 1925 (England); and *S. teteni* Wegner, 1911 (Germany). Family PALAEANTEDONIDAE: *Semiometra bohemica* Gislén, 1925 (Bohemia); *S. courvillensis* Valette, 1917 (France); *S. impressa* P. H. Carpenter 1881 (Sweden); *S. lenticularis* Schlüter 1878 (Holland); *S. minuta* Gislén (England); *S. plana* Brünnich-Nielsen, 1913 (north Germany; Denmark); *S. plana* var. *stellata* Gislén, 1925 (England); *S. pommerania* Gislén, 1924 (north Germany); *S. rowei* Gislén, 1924 (England); *S. scania* Gislén, 1924 (Sweden); *Hertha cava* Brünnich-Nielsen, 1913 (Denmark); *H. mystica* Hagenow, 1840 (north Germany; Belgium); *H. pygmea* Gislén, 1924 (north Germany); *H. suecica* Gislén, 1924 (Sweden); and *Palaeantedon danica* Brünnich-Nielsen, 1913 (Denmark).

Four additional species have not as yet been assigned to the genera now used; these are: *Actinometra batalleri* Astre, 1925 (Spain); *Antedon astellatus* Lehner, 1937 (Germany); *A. bellilensis* Valette, 1935 (north Africa); and *A. chateleti* Valette, 1933 (France).

In determining the systematic relationships of this new species the unidentifiable fragments and the species based upon brachials or arms may be disregarded. It is necessary, however, to consider the numerous species represented only by centrodorsals—assembled under the generic term *Glenotremites*. These species are divisible into two groups. In the first group the centrodorsal is columnar to conical, more rarely discoidal, and the cirrus sockets are large and prominent and arranged in columns, or if they are in a single row they show a distinct transverse ridge. Evidently this new species can not belong here. In the second group the centrodorsal is discoidal to hemispherical and the cirrus sockets are in crowded alternating rows, or if they are in a single row they are without sculpture. The new species is not closely related to any of the described species in this group.

The species in which at least the centrodorsal and the basal and radial circlets are preserved are distributed among the families Comasteridae, Solanocrinidae, Conometridae, Notocrinidae, and Palaeantedonidae. The new species can not belong to the family Comasteridae, in which the centrodorsal is much flattened with the sides never divided into radial areas, and the cirrus sockets are large or absent. It can not belong to the family Solanocrinidae, in which the centrodorsal is discoidal to columnar with the sides never divided into radial areas, and the cirrus sockets are large and arranged in columns or in a single row. It can not belong to the family Notocrinidae, in which the centrodorsal is conical to hemispherical with the sides not divided into radial areas, and the cirrus sockets are large. Finally, it can not belong to the family Conometridae, in the known species of

which the centrodorsal is conical or discoidal with the sides usually divided into definite radial areas by bare stripes or low ridges, each radial area having two columns of rather large cirrus sockets.

This leaves for consideration the family Palaeantedonidae. Gislén defines this family as including species with the centrodorsal varying from sharply flattened to hemispherical, the cirrus sockets small and arranged in closely crowded alternating rows, and the cirri composed of long segments. He says that the species are slender with 10 arms composed of moderately oblique brachials, and that synarthries and syzygies are well developed.

The present species agrees with this definition in having numerous small cirrus sockets; in having the cirri composed, at least in the basal portion, of long segments; in having 10 arms composed of moderately oblique brachials; and in having well developed synarthries and syzygies. The other details can not be determined.

It would seem, therefore, that this species falls within the family Palaeantedonidae, which includes the genera *Semiometra* Gislén (Upper Cretaceous to Eocene), *Hertha* Hagenow (Upper Cretaceous to Miocene), *Discometra* Gislén (Miocene), and *Palaeantedon* Gislén (Upper Cretaceous to Quaternary).

These genera are unfortunately differentiated by characters in the centrodorsal and articular faces of the radials that can not be made out in the present specimens. *Semiometra* appears to be ruled out; as in that genus the centrodorsal is low or flattened, the cirrus sockets are relatively large, and the size is much less. *Hertha* is composed of small species with the centrodorsal not exceeding 5 mm in diameter which have relatively larger cirrus sockets and much fewer cirri. In *Discometra* the centrodorsal is very much flattened, thick discoidal with a large bare dorsal pole. *Palaeantedon*, with a hemispherical centrodorsal, a small bare dorsal pole, and numerous closely set cirrus sockets arranged in alternating rows seems to offer characters nearest to those of the present specimens.

Palaeantedon is known from the Upper Cretaceous of Denmark (*danica* Brünnich-Nielsen); the Eocene of South Carolina (*caroliniana* Gislén); the Miocene of Algeria (*ambigua* Pomel, *cartenniensis* Pomel, *globosa* Pomel, *lineata* Pomel, and *soluta* Pomel); the Miocene of Italy (*minima* Noëlli); the Miocene of Hungary (*depressa* Gislén and *pannonica* Vadász); the Pliocene of Java (*weberi* Sieverts); and the Quaternary of Algeria (*rosacea* Pomel).

These specimens cannot be referred to *Palaeantedon* because of their very much more numerous cirri, the maximum number in that genus being about 50 (L) (in *P. pannonica*). It is probable that if other characters could be determined other differences would be found.

In 1925 Prof. Torsten Gislén created the genus *Gasterometra* based upon a much worn centrodorsal and radial pentagon from the Upper Cretaceous (probably Senonian) of Devon, England to which he gave the name of *Gasterometra polycirra*. He referred the genus *Gasterometra* to the family Palaeantedonidae. The various characters used in the diagnosis of the genus *Gasterometra* can not be made out in the present specimens. But *Gasterometra polycirra* is of large size with the hemispherical centrodorsal 9.2 mm in diameter and 4.2 mm high, and with its whole surface closely studded with a very great number—at least 300 (CCC)—very small cirrus sockets which are distributed in about 10 alternating rows.

In its large size and in the very large number of cirrus sockets *Gasterometra polycirra* is in general agreement with the present specimens, although in these the outline of the centrodorsal can not be traced and none of the cirrus sockets are visible. As *Gasterometra polycirra* and the species represented by the present specimens agree in the very large number of very slender cirri, and in this feature are quite unique among both fossil and recent comatulids, it is probable that they are related, though it is unlikely that they belong to the same genus.

Gislén noted that *Palaeantedon rosacea* Pomel is possibly, as suggested by Pomel himself, identical with *Antedon mediterranea*. In the present specimens the distal segments of the lower pinnules, a few short series of which are preserved in curved rows lying on the dorsal surface of the brachials, are exceedingly short, not longer than broad, with the proximal end constricted. They thus resemble, at least superficially, the lower pinnules found in the subfamily Heliometrinae of the family Antedonidae. In fact, the best general idea of the appearance of these specimens would be conveyed by comparing them to very large individuals of

a species of *Florometra* with exceedingly numerous and slender cirri, brachials with only slightly oblique ends, and short-segmented flexible distal as well as proximal pinnules. But it should be remembered that in the comatulids superficial similarity does not always indicate close relationship.

For the photographs reproduced on the plate I am indebted to Dr. Ray S. Bassler, head curator of geology, United States National Museum.

BOTANY.—*A new species of* Orcuttia *from Baja California.*[1] JASON R. SWALLEN, Bureau of Plant Industry, Soils, and Agricultural Engineering.

The genus *Orcuttia* Vasey was described in 1886 with a single species, *O. californica*, from Baja California. A second species was described by Vasey in 1891, from Chico, Calif. The genus was known only from these two rare species until recent years when both were collected in California and two new species in addition. A second species from Baja California was discovered in 1942 by Howard Scott Gentry.

Orcuttia fragilis Swallen, sp. nov.

Annua; culmi 15–40 cm longi, multinodosi, erecti vel decumbentes, geniculati, papillosi vel papilloso-pilosi, purpurascentes, e nodis superioribus breviter ramosis; folia 3.5–6.5 cm longa, 6–12 mm lata, plana, acuta, papillosa vel papilloso-pilosa; ligula obsoleta; paniculae densae, breves 5–10 mm latae, parte inferiori inclusa; spiculae 3–8-florae, 6–12 mm longae; glumae aequales, 7 mm longae, acuminatae, marginibus tenuibus hyalinis; lemma infimum 6–7 mm longum, acutum vel subacuminatum, mucronatum, pubescens et pilosum, minute dentatum; palea lemmate paulo brevior, dentata, carinis minute scabris, marginibus tenuibus, hyalinis; antherae 3 mm longae.

Annual; culms 15–40 cm long, many-noded, erect or usually ascending or decumbent at the base, incurved above, geniculate at the lower and middle nodes, the internodes rather short, of nearly equal length, prominently papillose or papillose-pilose, purple, in striking contrast to the pale green leaves, bearing short, appressed, flowering branches from the upper nodes; leaves 3.5–6.5 cm long, 6–12 mm wide, flat, acute, papillose or papillose-pilose, the division into sheath and blade not evident except for a slight constriction at the ligular area, the blade finally breaking off at this line; panicles dense, spikelike, all or partly enclosed in the upper leaves, the exserted portion 1–3 cm long, 5–10 mm wide, or those on the lower branches smaller; spikelets 3–8-flowered, 6–12 mm long; glumes equal, 7 mm long, acuminate, the margins thin, hyaline; lemmas pubescent, especially toward the base, and also sparsely pilose, the lowest 6–7 mm long, acute or subacuminate, the others successively smaller, minutely toothed, the midnerve excurrent as a short mucro; palea a little shorter than the lemma, dentate, minutely scabrous on the keels, the margins broad, thin, hyaline; anthers 3 mm long.

Type in the U. S. National Herbarium, no. 1865489, collected on playa, sandy clay; at Llano Dirai, Magdalena Plain, within the limits of the Sonoran Desert in southern Baja California by H. S. Gentry (no. 4192). "An abundant forage grass over the great flood-plain following rain storage. Reported excellent for cattle."

[1] Received May 20, 1944.

BOTANY.—*A new species of* Hemitelia *from Peru.*[1] WILLIAM R. MAXON, U. S. National Museum.

The ferns collected in Peru by Mrs. Ynes Mexia in 1931 include the following strongly characterized new species of *Hemitelia*. Among American members of Cyatheaceae it appears unique in indusium characters, notwithstanding the great diversity shown by members of the family in this respect, and I know of none with similar venation.

Hemitelia nervosa Maxon, sp. nov.

§*Cnemidaria*. Rhizomatis vel caudicis fragmentum solum adest, parte apicali dense paleacea, paleis lanceolato-subulatis, longe attenuatis, usque ad 2 cm longis, basi 3–4 mm latis, medio brunneis, scleroticis, lucidis, margine late albido-scariosis, subtiliter fimbriatis. Frons saltem 2-metralis; stipes ca. 70 cm longus, validus, basi curvata brunnea modice verrucosus, sursum antice profunde trisulcatus; lamina ubique nuda et glaberrima, oblonga, 1.3 m longa, ca. 60 cm lata, apice acuta, basin versus non angustata, imparipinnata, rhachi sulcata; pinnae remotae, latere utroque 11, basales oppositae, ceterae subopositae vel superiores alternae, omnes subaequales, ca. 30 cm longae, 6.5–7.5 cm latae, anguste oblongo-lanceolatae, apice acuminatae, basi subrotundae vel latissime cuneatae, pleraeque petiolulatae (3–8 mm), acumine excepto crasse serratis, serraturis 5–9 mm longis, 1.5–3 (4) mm altis, convexo-curvatis, antice apiculatis; venae usque ad acuminem ca. 40 jugae, utrinque elevatae, venula basali transverse conjunctae, arcu costali 3 vel 4 radiis longe exeuntibus, his varie inter se acute conjunctis; venulae laterales 6–10-jugae, obliquae, apicales breves, liberae, ceterae plerumque cum venulis oppositis et arcuum radiis irregulariter angulo acutissimo anastomosantes, venulis consociatis pellucidis saepe geminis; sori ca. 1.5 mm diam., 6–10-jugi, in zonam latam a costa remotam positi; indusia rotunda, plana, parva, tenere membranacea, primum subintegra et sporangiis numerossimis omnino operta, demum leviter lobata; receptacula magna, globosa, sessilia.

Type in the U. S. National Herbarium, nos. 1615531–533, collected in a gully at mouth of Río Santiago, above Pongo de Manseriche, Departamento de Loreto, Peru, altitude 300 meters, December 18, 1931, by Mrs. Ynes Mexia (no. 6291). Presumably the trunk was decumbent or weakly ascending, attaining a length of less than one meter.

Hemitelia nervosa differs widely from all previously known members of the subgenus or section *Cnemidaria*, especially in venation. The lateral veinlets are elongate, very oblique, and almost without exception unbranched. Of these, the three to five apical pairs are free and run to the curved margin of the serrature. The four or five lower pairs are variously joined to opposed veinlets from the next vein or to the branches running up from the costal arc. The common or combined veins running to the sinuses are variable in width, color, position, and structure, being sometimes single and simple, often single and very acutely once-forked, or not infrequently even distinctly paired. In addition to its curious venation *H. nervosa* is at once distinguished among *Cnemidaria* species by its sharply curvate-serrate margins.

In its flat, circular, delicately membranous indusium *H. nervosa* is unique within the genus, at least as represented in America. A few members of *Euhemitelia*, it is true, have indusia that are rounded in general outline, instead of semicircular, but these are species of distant relationship and the indusia are large, coarse, and divided into several spreading saccate lobes, thus widely different from *H. nervosa*.

[1] Published by permission of the Secretary of the Smithsonian Institution. Received May 20, 1944.

HEMITELIA NERVOSA MAXON

ORNITHOLOGY.—*The subspecies of the gnatcatcher* Polioptila albiloris.[1] PIERCE BRODKORB, University of Michigan. (Communicated by HERBERT FRIEDMANN.)

Study of the black-capped gnatcatchers of Mexico and Central America is complicated by marked sexual dimorphism and in most cases by equally marked seasonal plumage changes. Until recently seasonal changes were not known to occur or were misunderstood. As a result, the several species and subspecies were hopelessly confused, some authors even going so far as to reduce them to a single wide-ranging species. As clearly demonstrated by van Rossem,[2] however, the black-capped gnatcatchers are divisible into three major groups which may be summarized as follows:

A. Cap of male black only in summer; winter male gray-capped like the female at all seasons.
Polioptila nigriceps (northwestern Mexico)
AA. Cap of male black at all seasons.
B. Loral and superciliary regions of male black in summer, partially white only in winter *Polioptila albiloris* (southern Mexico and northern Central America)
BB. No season change; loral and superciliary regions always entirely white.
Polioptila plumbea (Central and South America)

Van Rossem recognized the *nigriceps* forms as constituting a specific unit, but he reluctantly combined the *albiloris* forms in the same specific unit with *bilineata*, because the two groups were said by others to intergrade. Zimmer[3] placed *albiloris* in a separate specific unit from *bilineata*, which latter he considered a subspecies of *Polioptila plumbea*. He stated that *albiloris* and *Polioptila plumbea superciliaris* occur together without intergradation in parts of Nicaragua and Costa Rica. In view of the confusion that existed previous to van Rossem's work, I am inclined to follow Zimmer in disregarding the earlier claims of intergradation between these two forms, especially since I find no evidence of intergradation among the specimens examined by me.

The species here understood as *Polioptila albiloris* inhabits parts of Mexico and Central America below 1,000 meters altitude, from the state of Nayarit to Costa Rica. It is a bird of arid regions and is thus largely confined to the Pacific side of the continent. It occurs also in arid localities on the Atlantic side in northwestern Oaxaca, in the Grand Valley of Chiapas, on the tip of the Yucatán Peninsula, in the Motagua Valley of Guatemala, and in the interior of Honduras. Within the area outlined above the known distribution of the species is spotty. Several of the apparent gaps in its range are undoubtedly due to lack of exploration. Others are real and divide the range of the species into at least three isolated regions. One such area is the tip of the Yucatán Peninsula. A second is the remainder of the Mexican range of the species outlined above. The third is the Central American part of the range. The last area consists of two sections, on the Atlantic and Pacific sides of Central America, respectively. It is as yet unknown whether these two colonies meet.

Some order may be made of the spotty nature of the range of *Polioptila albiloris* when the distribution of other species of the genus is considered. On the Pacific side the northern limits of *albiloris* are practically coterminous with the southern limits of *Polioptila nigriceps nigriceps*. The southern boundaries of the range of *albiloris* overlap slightly the northern boundaries of the range of *Polioptila plumbea superciliaris*. On the Atlantic side the range of *albiloris* ceases approximately at the beginning of the ranges of *Polioptila caerulea deppei*, *Polioptila caerulea nelsoni*, and *Polioptila plumbea superciliaris*, from north to south, respectively.

In a few places *Polioptila albiloris* has been recorded as occurring together with other resident gnatcatchers. It has been recorded with *Polioptila caerulea deppei* at Tehuantepec and Santa Efigenia, Oaxaca, and at Gualán, Guatemala. *Polioptila caerulea caerulea* is not an uncommon winter visitant in these regions, and since the differences between *deppei* and *caerulea* are

[1] Received March 25, 1944.
[2] *Concerning some Polioptilae of the west coast of Middle America*, Auk 48, 33–39. 1931.
[3] *Studies of Peruvian birds: No. XLII*, Amer. Mus. Nov., No. 1168: 1–6. 1942.

not very pronounced, it is possible that the above records of *deppei* may have been based on migrants of *caerulea*. All authentic specimens of *deppei* which I have examined are from the Gulf lowlands of Mexico.

Polioptila albiloris albiventris has been recorded from Cozumel Island, where *P. caerulea cozumelae* breeds. This record, based upon two Gaumer-taken specimens, is perhaps open to doubt, since no subsequent collector has found the black-capped species on Cozumel.

Nelson and Goldman collected both *Polioptila albiloris* and *P. caerulea nelsoni* at San Vicente, Chiapas, on the edge of the range of both species.

In parts of Nicaragua and in northwestern Costa Rica *P. albiloris* and *P. plumbea superciliaris* occur together.

In spite of the isolation of several of the populations of *Polioptila albiloris*, subspecific differentiation has not progressed far. This fact possibly argues for the comparatively recent expansion of the species into suitable areas which were at the time unoccupied by other members of the genus.

Acknowledgments.—For the use of material I am indebted to Merriam L. Miles and to the authorities of the Academy of Natural Sciences of Philadelphia, the Donald R. Dickey collection at the University of California at Los Angeles, the Chicago Natural History Museum, the U. S. Fish and Wildlife Service, the Museum of Comparative Zoology, and the United States National Museum. This study was aided by a grant from the Faculty Research Fund by the board of governors of the Horace H. Rackham School of Graduate Studies in the University of Michigan.

Polioptila albiloris vanrossemi, n. subsp.

Polioptila nigriceps [nec Baird] Lawrence, U. S. Nat. Mus. Bull. 4: 12. 1876 (Quiotepec, Tapana [=Tapanatepec], and Santa Efigenia, Oaxaca).—Salvin and Godman, Aves, Biol. Centrali-Amer. 1: 52, part. 1879 (Quiotepec, Tapana, and Santa Efigenia).—Sumichrast, Naturaleza 5: 241. 1882 (Quiotepec, Tapanatepec, and Santa Efigenia, Oaxaca; Tonalá, Chiapas).—Ridgway, Proc. U. S. Nat. Mus. 5: 387, part. 1882 (Oaxaca and Tehuantepec).—Herrera, Naturaleza, ser. 2, 3: 196, part. 1899 (Quiotepec, Tapana, and Santa Efigenia).—Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 729, part. 1904 (Cuicatlán, Quiotepec, Puerto Ángel, Tehuantepec, Huilotepec, Tapana, and Santa Efigenia, Oaxaca).—Bangs and Peters, Bull. Mus. Comp. Zool. 68: 398. 1928 (Chivela and Tapanatepec, Oaxaca).

Polioptila nigriceps nigriceps Hellmayr, Tierreich, pt. 18: 25, part. 1903 (Oaxaca and Tehuantepec).—Hellmayr, *in* Wytsman, Genera avium, pt. 17: 17, part. 1911 (Oaxaca).

Polioptila bilineata nigriceps Griscom, Bull. Mus. Comp. Zool. 75: 398, part. 1934 (Coyuca, Guerrero).[4]

Polioptila albiloris [nec Sclater and Salvin] Lawrence, U. S. Nat. Mus. Bull. 4: 12. 1876 (Santa Efigenia and Tehuantepec City, Oaxaca).—Salvin and Godman, Aves, Biol. Centrali-Amer. 1: 53, part. 1879 (Tehuantepec and Santa Efigenia).—Sumichrast, Naturaleza 5: 241. 1882 (Tehuantepec, Cacoprieto, and Santa Efigenia, Oaxaca).—Ridgway, Proc. U. S. Nat. Mus. 5: 387, part. 1882 (Tehuantepec, Santa Efigenia, and Tapana, Oaxaca).—Sharpe, Cat. Birds Brit. Mus. 10: 454, part. 1885 (Tehuantepec).—Ridgway, Man. North Amer. Birds, p. 569, part. 1887 (Tehuantepec).—Herrera, Naturaleza, ser. 2, 3: 196, part. 1899 (Tehuantepec and Santa Efigenia).—Sharpe, Hand-list 3: 242, part. 1901 (west Mexico).—Hellmayr, Tierreich, pt. 18: 28, part. 1903 (Isthmus of Tehuantepec).—Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 725, part. 1904 (Cuicatlán, Tehuantepec, Huilotepec, Santa Efigenia, and Tapana, Oaxaca; description; measurements; bibliography).

Polioptila albiloris albiloris Hellmayr, *in* Wytsman, Genera avium, pt. 17: 16, part. 1911 (Oaxaca).—Zimmer, Amer. Mus. Nov., No. 1168: 1, 2, 6, part. 1942 (Tapana and Santa Efigenia; criticism; measurements).

Polioptila bilineata albiloris Griscom, Amer. Mus. Novit., No. 414: 7, part. 1930 (Tehuantepec and Chivela; criticism).—van Rossem, Auk 48: 34, part. 1931 (Atlantic drainage of southern Mexico).—Dickey and van Rossem, Publ. Field Mus. Nat. Hist., Zool. ser., 23: 462, in text, part. 1938 (Atlantic drainage of Chiapas).

Polioptila plumbea albiloris Hellmayr, Publ. Field Mus. Nat. Hist., Zool ser., 13, pt. 7: 504, part. 1934 (southern Mexico).

Polioptila bilineata [nec Bonaparte] Sharpe, Hand-list 3: 242, part. 1901 (Mexico).

Polioptila bilineata bairdi [nec Ridgway] van Rossem, Auk 48: 35, part. 1931 (San Blas, Nayarit).—Dickey and van Rossem, Publ. Field Mus. Nat. Hist., Zool. ser., 23: 462, in text, part. 1938 (San Blas).

Polioptila plumbea bairdi Hellmayr, Publ. Field Mus. Nat. Hist., Zool. ser., 13, Pt. 7 505, part. 1934 (Santiago and San Blas, Nayarit; Iguala and Tierra Colorada,

[4] The specimens from Chilpancingo prove upon examination to be *Polioptila caerulea nelsoni*.

Guerrero; Sierra Santo Domingo, Tehuantepec, and Salina Cruz, Oaxaca).—Blake and Hanson, Publ. Field Mus. Nat. Hist., Zool. ser. 22: 542. 1942 (Apatzingán, Michoacán).

Type.—U.S.N.M. 54441; adult male; Quiotepec, District of Cuicatlán, Oaxaca; August 8, 1868; Francis Sumichrast, original number 12.

Characters.—Agrees with other races of *Polioptila albiloris* in having the cap of the male constantly black after the postjuvenal molt; loral and superciliary regions of male entirely black in breeding plumage; loral and superciliary regions of both sexes largely white in winter but with a dark spot (black in male, dusky in female) at anterior corner of eye and with a broad dark postocular stripe.

Differs from other subspecies of *Polioptila albiloris* in having the wing and especially the tail longer; the tail always longer than the wing. Differs further from *P. albiloris albiventris* in darker dorsal and ventral coloration.

Range.—Southern Mexico in the interior and in the Pacific lowlands, from Nayarit (Santiago and San Blas), Michoacán, (Apatzingán), Guerrero (Coyuca, Acapulco, Tierra Colorada, and Iguala), Oaxaca (Quiotepec, Cuicatlán, Puerto Ángel, Tehuantepec, Huilotepec, Salina Cruz, Chivela, Sierra Santo Domingo, Santa Efigenia, and Tapanatepec), to Chiapas (Arriaga, Tonalá, Tuxtla Gutiérrez, San Bartolomé, San Vicente, and Chicomuselo).

Remarks.—The characters of this form are best developed in the District of Cuicatlán, northwestern Oaxaca. Whether its range is continuous from that district across to the Pacific coast is at present unknown. Specimens from the coast, from Acapulco to Puerto Ángel, are slightly atypical. Those from the Grand Valley of Chiapas, while still less typical, are yet closer to the Oaxaca birds than they are to Central American specimens. Birds from the Isthmus of Tehuantepec and the Pacific coast of western Chiapas, on the other hand, resemble *bairdi* at least as much as they do *vanrossemi*. Nevertheless, in view of the hiatus in the range of the species along the Pacific coast between the isthmus and El Salvador, I have thought it expedient to refer the whole Mexican colony to *vanrossemi*.

Zimmer suspected the existence of a long-tailed Mexican subspecies, although the only specimens which he was able to examine were from the intergrading population of the Isthmus of Tehuantepec.

Specimens examined.—Guerrero (Acapulco, 3). Oaxaca (Quiotepec, 1, type; Cuicatlán, 3; Puerto Ángel, 1; Chivela, 3; Tehuantepec, 4; Huilotepec, 2; Santa Efigenia, 2; Tapanatepec, 1). Chiapas (Arriaga, 4; Tonalá, 9; Tuxtla Gutiérrez and vicinity, 11; San Bartolomé, 2; San Vicente, 1; Chicomuselo, 2). Total, 49.

Polioptila albiloris albiventris Lawrence

Polioptila albiventris Lawrence, Ann. New York Acad. Sci. 3: 273. 1885 (Temax, Yucatán; original description).—Ridgway, Man. North Amer. Birds, p. 569. 1887 (Yucatán; characters).—Stone, Proc. Acad. Nat. Sci. Philadelphia, 1890: 211 (Progreso, Yucatán).—Hellmayr, Tierreich, pt. 18: 24, 1903 (Yucatán).—Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 729. 1904 (Temax and Progreso; characters; measurements; bibliography).

Polioptila nigriceps albiventris Hellmayr, *in* Wytsman, Genera avium, pt. 17: 16. 1911 (Yucatán).

Polioptila bilineata albiventris Griscom, Amer. Mus. Nov., No. 414: 7. 1930 (outer third of Yucatán Peninsula; criticism).

Polioptila plumbea albiventris Hellmayr, Publ. Field Mus. Nat. Hist., zool. ser., 13, pt. 7: 503. 1934 (Temax, Mérida, Progreso, and Cozumel Island; criticism; characters).

Polioptila albiloris albiventris Zimmer, Amer. Mus. Nov., No. 1168: 2, 6. 1942 (Temax; criticism; type in American Museum).

Polioptila bilineata [nec Bonaparte] Boucard, Proc. Zool. Soc. London, 1883: 439 (Progreso).—Salvin, Ibis, ser. 5, 6: 246. 1888 (Cozumel Island).

Polioptila nigriceps [nec Baird] Sharpe, Cat. Birds Brit. Mus. 10: 447, part. 1885 (Mérida, Yucatán).

Characters.—Paler on dorsal and ventral surfaces than any of the other subspecies of *Polioptila albiloris*. Agrees with *vanrossemi* in always having the tail longer than the wing, but differs in having the wing and especially the tail of lesser dimensions.

Range.—Northern Yucatán (Progreso, Temax, and Mérida). Cozumel Island?.

Specimens examined.—Yucatán (Progreso, 12).

Polioptila albiloris albiloris Sclater and Salvin

Polioptila albiloris Sclater and Salvin, Proc. Zool. Soc. London, 1860: 298 (original description; Motagua Valley, Guatemala).—Salvin and Sclater, Ibis 2: 397. 1860 (Choacus [= Chuacús], Guatemala; type locality).—Owen, Ibis 3: 61.

pl. 2, fig. 3. 1861 (Choacus; description of nest and eggs).—Gray, Hand-list 1: 237. 1869 (Guatemala).—Sclater and Salvin, Nomenclator Avium Neotrop., p. 4. 1873.—Salvin and Godman, Aves, Biol. Centrali-Amer. 1: 53, pl. 5, figs. 1, 2. 1879 (Chuacús).—Ridgway, Proc. U. S. Nat. Mus. 5: 387, part. 1882 (Guatemala).—Sharpe, Cat. Birds Brit. Mus. 10: 454, part. 1885 (Chuacús; types in British Museum; description; bibliography).—Ridgway, Man. North Amer. Birds, p. 569, part. 1887 (Guatemala).—Herrera, Naturaleza, ser. 2, 3: 196, part. 1899 (Guatemala).—Hellmayr, Nov. Zool. 7: 536, in text. 1900 (criticism).—Sharpe, Hand-list 3: 242, part. 1901 (Guatemala).—Hellmayr, Tierreich, pt. 18: 28, part. 1903 (Guatemala).—Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 725, part. 1904 (Chuacús; bibliography).—Dearborn, Publ. Field Mus. Nat. Hist., orn. ser., 1: 136. 1907 (E. Rancho and Gualán, Guatemala).

Polioptila albiloris albiloris Hellmayr, *in* Wytsman, Genera Avium, pt. 17: 16, part. 1911 (Chuacús).—Zimmer, Amer. Mus. Nov., No. 1168: 1, 2, 6, part. 1942 (Progreso, Guatemala; criticism; measurements).

Polioptila bilineata albiloris Griscom, Amer. Mus. Nov., No. 414: 7, part. 1930 (Motagua Valley, from Progreso to Gualán, Guatemala; criticism; reduces *nigriceps*, *restrica*, and *bairdi* to synonymy).—van Rossem, Auk 48: 34, part. 1931 (interior Guatemala; criticism; measurements; seasonal changes).—Griscom, Bull. Amer. Mus. Nat. Hist. 64: 288. 1932 (Progreso, Guatemala).—Carriker and de Schauensee, Proc. Acad. Nat. Sci. Philadelphia 87: 439. 1935 (Gualán, [San Pablo near] Zacapa, El Rancho, and Marajuma, Guatemala).—Dickey and van Rossem, Publ. Field Mus. Nat. Hist., zool. ser., 23: 462, in text, part. 1938 (Atlantic drainage of northern Central America; criticism).

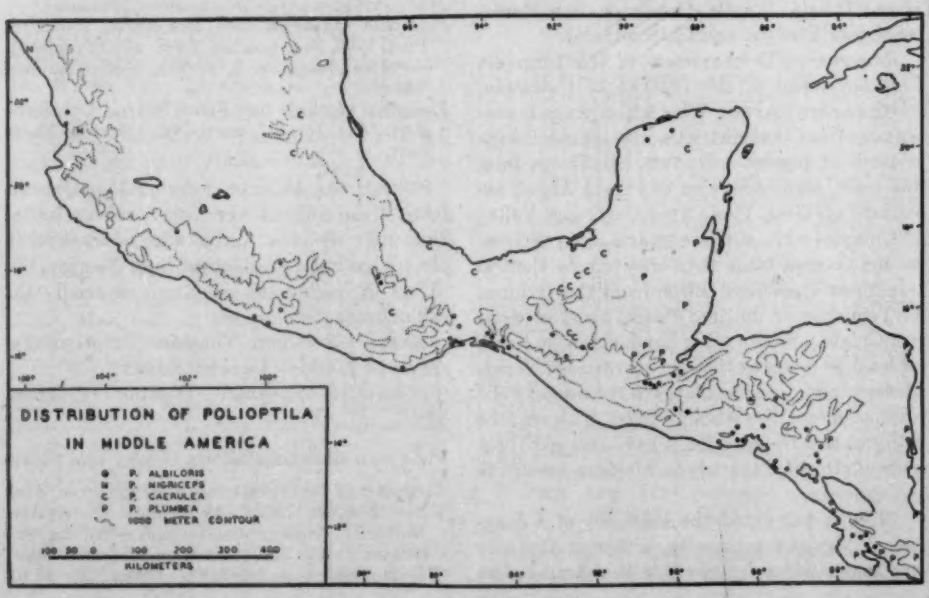
Polioptila plumbea albiloris Hellmayr, Publ. Field Mus. Nat. Hist., zool. ser., 13, pt. 7: 504, part. 1934 (Chuacús, El Rancho, and Gualán; bibliography).

Polioptila bilineata [nec Bonaparte] Stone, Proc. Acad. Nat. Sci. Philadelphia 84: 331. 1932 (Cantarranas, Honduras).

Polioptila bilineata bairdi [nec Ridgway] Dickey and van Rossem, Publ. Field Mus. Nat. Hist., zool. ser., 23: 461, part. 1938 (Lake Guija and San José del Sacare, El Salvador).

Characters.—Differs from *Polioptila albiloris albiventris* in darker dorsal and ventral coloration and in having the tail but little if any longer than wing (tail usually shorter than wing). Differs from *Polioptila albiloris vanrossemi* in having a shorter wing and much shorter tail.

Range.—Motagua Valley of Guatemala (Chuacús, Marajuma, Progreso, El Rancho, San Pablo, and Gualán), the interior of El Salvador (Laguna Guija and San José del Sacare), and the interior of Honduras (Monte Redondo, Comayaguela, Cerro Cantoral, San



Lorenzo, Montaña Vasquez, Hatillo, Cantarranas, and La Flor Archaga).

Specimens examined.—Guatemala (Gualán, 5; San Pablo, 1; El Rancho, 9; Progreso, 4; Marajuma, 1). El Salvador (Lake Guija, 3; San José del Sacare, 1). Honduras (Monte Redondo, 8; Comayaguela, 2; La Flor Archaga, 5; San Lorenzo, 3; Hatillo, 2; Montaña Vasquez, 1; Cerro Cantoral, 1). Total 46.

Polioptila albiloris bairdi Ridgway

Polioptila bairdi Ridgway, Proc. Biol. Soc. Washington **16**: 110. Sept. 30, 1903 (original description; San Juan del Sur, Nicaragua, type in U. S. National Museum; Costa Rica); U. S. Nat. Mus. Bull. 50, pt. 3: 726. 1904 (Realejo, Grenada, Sucuyá, and San Juan del Sur, Nicaragua; Liberia, Volcán de Miravalles, and Cartago [?], Costa Rica; description; measurements; bibliography).—Carriker, Ann. Carnegie Mus. **6**: 751. 1910 (Bagaces, Miravalles, Bebedero, and Ciruelas, Costa Rica).

Polioptila bilineata bairdi van Rossem, Auk **48**: 35, part. 1931 (Costa Rica, Nicaragua, and El Salvador; criticism; characters; measurements; seasonal changes).—Dickey and van Rossem, Publ. Field Mus. Nat. Hist., zool. ser., **23**: 461, part. 1938 (Lake Olomega, Río San Miguel, Volcán de San Miguel, La Unión, Volcán de Conchagua, Río Goascorán, Divisadero, Puerto del Triunfo, Zapotitán [?], Barra de Santiago [?], and Colima [?], El Salvador; northwestern Costa Rica; criticism; plumages; color of soft parts; habits; food).

Polioptila plumbea bairdi Hellmayr, Publ. Field Mus. Nat. Hist., zool. ser., **13**, pt. 7: 505, part. 1934 (La Unión, El Salvador; Nicaragua; Bebedero, Bagaces, Las Cañas, and Miravalles, Costa Rica; criticism; bibliography).

Polioptila albiloris [nec Sclater and Salvin] Baird, Review Amer. Birds, p. 70. 1864 (Grenada and Realejo, Nicaragua; west coast of Central America).—Ridgway, Proc. U. S. Nat. Mus. **5**: 387, part. 1882 (Realejo, Nicaragua; criticism).—Nutting, Proc. U. S. Nat. Mus. **6**: 373. 1883 (San Juan del Sur, Nicaragua).—Sharpe, Cat. Birds Brit. Mus. **10**: 454, part. 1885 (La Unión, El Salvador).—Ridgway, Man. North Amer. Birds, p. 569, part. 1887 (Salvador; Nicaragua).—Zeledón, Anal. Mus. Nac. Costa Rica **1**: 105. 1887 (Liberia and Cartago [?], Costa Rica).—Herrera, Naturaleza, ser. 2, **3**: 196, part. 1899 (Nicaragua).—Hellmayr, Tierreich, pt. 18: 28, part. 1903 (Nicaragua; Miravalles, Costa Rica).

Polioptila bilineata albiloris Griscom, Amer. Mus. Nov., No. 414: 7, part. 1930 (northwest Costa Rica; western Nicaragua; criticism).

Polioptila albiloris albiloris Zimmer, Amer. Mus. Nov., No. 1168: 1, 2, 6, part. 1942 (Matagalpa, León, Calabasas, Volcán de Chinandega, 4 miles north of Chinandega, San Rafael del Norte, Corinto, and Savana Grande, Nicaragua; Bebedero, Las Cañas, and Bagaces, Costa Rica; criticism; measurements).

Polioptila bilineata [nec Bonaparte] Salvin and Godman, Aves, Biol. Centrali-Amer. **1**: 52, part. 1879 (La Unión, E. Salvador).—Nutting, Proc. U. S. Nat. Mus. **6**: 380, part. 1883 (Sucuyá, Nicaragua).—Sharpe, Handlist **3**: 242, part. 1901 (Central America).

Polioptila nigriceps [nec Baird] Salvin and Godman, Aves, Biol. Centrali-Amer. **1**: 52, part. 1879 (La Unión, El Salvador).—Sharpe, Cat. Birds Brit. Mus. **10**: 447, part. 1885 (La Unión).—Herrera, Naturaleza, ser. 2, **3**: 196, part. 1899 (San Salvador).—Sharpe, Hand-list **3**: 241, part. 1901 (Salvador).—Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 729, part. 1904 (Pacific coast of Central America).

Polioptila nigriceps nigriceps Hellmayr, Tierreich, pt. 18: 25, part. 1903 (San Salvador; Bebedero, Costa Rica); *in* Wytsman, Genera Avium, pt. 17: 17, part. 1911 (Salvador).

Polioptila leucogastra [nec Wied] Ridgway, Proc. U. S. Nat. Mus. **5**: 387, 388, part. 1882 (Grenada, Nicaragua).

Polioptila nigriceps restricta [nec Brewster] Hellmayr, Nov. Zool. **7**: 536–538. 1900 ([Bebedero,] Costa Rica).

Polioptila restrica Sharpe, Hand-list **3**: 241, part. 1901 (Costa Rica?).

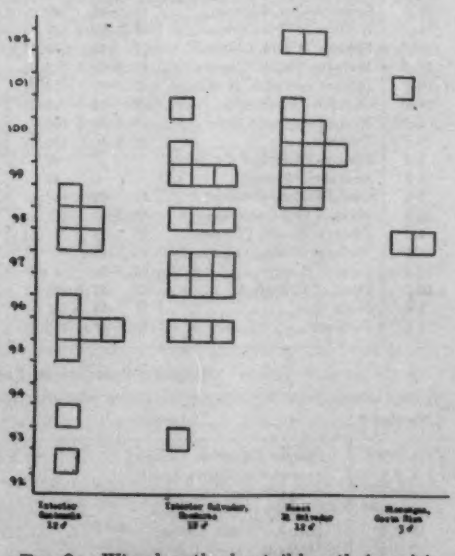


FIG. 2.—Wing length plus tail length (mm.) in *Polioptila albiloris albiloris* and *P. a. bairdii*. Each square represents one specimen.

Polioptila superciliaris superciliaris [nec Lawrence] Ridgway, U. S. Nat. Mus. Bull. 50, pt. 3: 727, part. 1904 (La Unión, El Salvador).
Polioptila ———— (?) Underwood, Ibis, ser. 7, 2: 432. 1895 (Miravalles, Bebedero, and Bagaces, Costa Rica).

Characters.—Differs from *Polioptila albiloris albiloris* only in slightly longer wing and tail.

Range.—Pacific lowlands of eastern El Salvador (west to the Río Lempa), Nicaragua, and northwestern Costa Rica (east to the Río Tenorio).

Remarks.—Zimmer synonymized *bairdi* with *albiloris*, since he was unable to find any stable character by which to separate it. Coastal birds tend to have both the wing and the tail longer than those *albiloris* from the interior, but only slightly more than half of my specimens can be determined by using the measurements of the wing and tail separately. By adding the individual wing and tail measurements, however, a clear division results. All the males from the coast of El Salvador have a wing-plus-tail measurement of 98.5 mm. or more, whereas that measurement in *albiloris* from the Motagua Valley of Guatemala is 98.5 mm. or less. Birds from interior El Salvador and interior Honduras are somewhat intermediate, but are closer to *albiloris* than to the coastal race.

The single Nicaraguan specimen examined (the type of *bairdi*) and the few skins from Costa Rica seem to agree fairly well with those from the coast of El Salvador, but the series is not ample enough to demonstrate this conclusively. Examination of larger series from southern Nicaragua and from Costa Rica, is desirable, since the possibility exists that *Polioptila albiloris albiloris* may cross over to the Pacific side in that region, as several other Caribbean forms do. In that event the name *bairdi* would become a synonym of *albiloris*, and the coastal birds of El Salvador would need another name.

Specimens examined.—El Salvador (Puerto del Triunfo, 1; Volcán de San Miguel, 1; Río San Miguel, 5; Divisadero, 9; Laguna Olomega, 6; Volcán de Conchagua, 2; Río Goascorán, 1). Nicaragua (San Juan del Sur, 1, type). Costa Rica (Punta Piedra, 5). Total, 31.

TABLE 1.—MEASUREMENTS (IN MM.) OF POLIOPTILA ALBILORIS

Number	Locality	Wing	Tail	Culmen	Wing plus tail
3 ♂	District Cuicatlán, Oaxaca	48.5–52 (50.0)	52.5–57.5 (54.7)	12.5–13 (12.8)	101 –109.5 (104.7)
3 ♂	Acapulco to Puerto Ángel	46 –50 (48.5)	47.5–53.5 (50.5)	13.5–14 (13.8)	93.5–103 (99.0)
10 ♂	Grand Valley, Chiapas	48 –52 (50.0)	48.5–53 (51.4)	13 –14 (13.5)	96.5–105 (101.4)
6 ♂	Isthmus of Tehuantepec	47.5–50.5 (49.4)	47 –50.5 (48.6)	13 –14 (13.4)	95.5–101 (98.0)
9 ♂	District Tonalá, Chiapas	47 –51 (49.1)	48 –51.5 (49.8)	13.5–15 (14.4)	97 –101 (98.6)
12 ♂	Motagua Valley, Guatemala	47.5–49.5 (48.6)	44.5–49.5 (47.5)	13.5–14 (13.8)	92.5– 98.5 (96.1)
18 ♂	Interior Salvador, Honduras	48 –51 (49.3)	44.5–50 (48.0)	12.8–15 (13.5)	93 –100.5 (97.3)
14 ♂	Coast of El Salvador	49 –51 (50.1)	48.5–51 (49.7)	12.5–14.5 (13.9)	98 –102 (99.8)
4 ♂	Nicaragua, Costa Rica	49.5–52.5 (50.7)	46.5–48.5 (47.6)	14 –14.5 (14.2)	97.5–101 (98.7)
8 ♂	Yucatán	44.5–48 (46.8)	45.5–50.5 (48.6)	12 –14 (13.1)	90 –98 (95.4)
1 ♀	District Cuicatlán, Oaxaca	49	51.5	12.5	100.5
1 ♀	Acapulco, Guerrero	46	48.5	12.5	94.5
6 ♀	Grand Valley, Chiapas	46 –49.5 (47.8)	47.5–50.5 (49.3)	13 –14 (13.5)	93.5– 99 (97.1)
6 ♀	Isthmus of Tehuantepec	45.5–49 (47.6)	47 –50 (48.2)	12.5–13.5 (13.1)	93 – 98.5 (95.6)
4 ♀	District Tonalá, Chiapas	46 –49 (47.3)	47 –51.5 (48.4)	13.5–14.5 (14.1)	93.5–100.5 (95.6)
8 ♀	Motagua Valley, Guatemala	45.5–49 (47.1)	45.5–48 (46.6)	13.5–14 (13.6)	91.5– 95 (93.6)
7 ♀	Interior Honduras	45.5–51 (47.7)	45 –48.5 (46.3)	12 –14.5 (13.3)	91– 97 (94.0)
10 ♀	Coast of El Salvador	47 –52.5 (48.2)	44.5–50 (47.7)	13 –14 (13.4)	91.5–102.5 (95.9)
2 ♀	Costa Rica	47 –48.5 (47.8)	46.5–47.5 (47.0)	13 –14.5 (13.8)	94.5–95 (94.8)
4 ♀	Yucatán	45.5–47.5 (46.3)	48.5–49 (48.8)	12.8–13.5 (13.2)	94 – 96 (95.0)

TABLE 2.—PROPORTIONS (PERCENT) IN POLIOPTILA ALBILORIS

Number	Locality	Wing/Tail	Culmen/Tail
4 ♂ ♀	District Cuicatlán, Oaxaca	90.4– 95.1 (92.4)	22.6–24.8 (23.7)
4 ♂ ♀	Acapulco to Puerto Ángel	92.8– 99.0 (95.8)	25.8–28.4 (27.0)
16 ♂ ♀	Grand Valley, Chiapas	92.1–100.0 (97.1)	25.0–28.3 (26.7)
12 ♂ ♀	Isthmus of Tehuantepec	95.3–106.4 (100.2)	26.7–28.1 (27.3)
13 ♂ ♀	District Tonalá, Chiapas	93.2–103.1 (98.0)	27.0–33.3 (29.3)
20 ♂ ♀	Motagua Valley, Guatemala	97.0–107.9 (101.9)	27.3–31.5 (29.3)
25 ♂ ♀	Interior Salvador, Honduras	96.0–110.9 (102.9)	26.1–32.3 (28.3)
24 ♂ ♀	Coast of El Salvador	96.0–105.6 (100.9)	25.0–30.3 (28.0)
6 ♂ ♀	Nicaragua, Costa Rica	98.9–106.2 (104.0)	27.4–31.2 (29.7)
12 ♂ ♀	Yucatán	92.9– 98.9 (97.5)	24.0–28.6 (26.9)